Teacher's Guide
Investigating the Earth

Revised Edition / American Geological Institute

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Teacher's Guide

Investigating the Earth

Revised Edition

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Miles F. Harris

Dale T. Hesser

J. Allen Hynek

William H. Matthews, III

Chalmer J. Roy

James W. Skehan, S.J.

Robert E. Stevenson

Sponsored by the American Geological Institute and based on the original Earth Science Curriculum Project.

Authors

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Preface to Teacher's Guide

This Teacher's Guide for *Investigating the Earth* is written for science teachers everywhere — the adventuresome, the innovative, the creative — all of those dedicated teachers who search for new and better ways of teaching science.

In developing the Teacher's Guide to *Investigating the Earth*, the authors focused attention on the needs of teachers who: (1) teach in relative isolation from other earth science teachers, (2) are inexperienced in teaching earth science, (3) lack a strong undergraduate education in the earth sciences, (4) have limited science equipment and facilities, (5) work with students with a wide range of interests and abilities, and (6) have little experience in teaching science through an investigative approach. Most of the ideas in this Teacher's Guide should also be of value to the experienced earth science teacher.

Teachers experienced with the first edition of the text will find the current guide reduced in size. This has been accomplished mainly by omitting material duplicated in the text and by shortening the text itself. (The amount of physical science has been greatly reduced.) You can be confident that all essential guidance and information have been retained in the Guide.

The revised text presents a unified course in earth science. Emphasis throughout is on concepts and principles essential to an understanding of the dynamics and history of the earth. The investigations are carefully designed to develop the students' understanding of these principles and concepts. You are encouraged to develop investigations of factors in your own environment. Certainly every school should make use of really unique local circumstances. Suggestions in this regard are included in the text, this guide, and in many of the references in both the text and guide.

This volume contains basic "how-to-do-it" suggestions, examples, analogies, demonstrations, help with laboratory investigations, notes on teaching strategy, answers to questions and problems, help with the inquiry approach, suggested readings, and audiovisual aids.

The introductory section explains the features and uses of this volume. We hope you will find the Teacher's Guide a convenient and valuable source of assistance in your teaching, and we will welcome your comments and suggestions.

The Authors

General Time Table

	Chapter	Time
UNIT ONE 5–7 WEEKS	1	8–10 DAYS
	2	10–12 DAYS
	3	8–11 DAYS
UNIT TWO 8–10 WEEKS	4	4–6 DAYS
	5	10 DAYS
	6	10–12 DAYS
	7	8–10 DAYS
	8	5–8 DAYS
UNIT THREE 6–8 WEEKS	9	5–7 DAYS
	10	6–8 DAYS
	11	5–6 DAYS
	12	5–7 DAYS
	13	6–8 DAYS
	14	6–10 DAYS
UNIT FOUR 4–6 WEEKS	15	5–7 DAYS
	16	6–8 DAYS
	17	6–8 DAYS
	18	5–7 DAYS
UNIT FIVE 4–5 WEEKS	19	3–5 DAYS
	20	5–7 DAYS
	21	4–6 DAYS
	22	4–6 DAYS
TOTAL 27–36 weeks		

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Introduction

The nature of *Investigating the Earth*

Investigating the Earth is a contemporary, interdisciplinary approach to the study of the earth and its environment. Technical vocabulary is kept to a minimum, yet *Investigating the Earth* reflects the latest thinking of prominent earth scientists. Topics of current interest — space flights, the plate tectonics theory, and environmental concerns — are incorporated in both text and laboratory investigations.

Investigating the Earth is student-oriented. Laboratory investigations form a major portion of the course. Additional "Action" assignments provide further opportunities for students to build inquiry skills.

A basic assumption of the course is that ideas in earth science have social relevance. Air and water pollution, weather control, nuclear testing, and shrinking fossil fuel reserves are examples of issues where earth science, politics, and society do not always agree. Students with a background in earth science are better prepared to be responsible citizens.

Themes of *Investigating the Earth*

Investigating the Earth contains a cluster of ideas basic to the study of earth science. The themes shape the perspective students develop from the course. Throughout the year students return to these themes as they build insight and refresh their understanding.

Science as inquiry

Science is presented throughout as inquiry, as a search for new and more accurate knowledge about the earth. At the end of each chapter a special section focuses on the unsolved problems at the frontiers of scientific knowledge.

Comprehension of scale

A goal of this course is to help students develop concepts of scale in the real world. A parallel theme is helping students develop skill in devising and using models. Earth scientists use a variety of scales, and so will the students. For example, investigations of the structure of minerals use the size scale of atomic particles, whereas astronomy questions the size of the universe.

Prediction

Prediction is a goal of most scientific inquiry. Repeatedly during the year students practice making predictions based on logic and what they already know. Then they test their predictions in an activity or investigation.

Uniformity of process

This theme is prediction turned backwards in time. You can interpret events in the past only if you assume that the same fundamental chemical reactions and physical processes have operated throughout earth history. Students faced with fragmentary or limited data learn to use the present as a key to interpreting the past.

Universality of change

This course emphasizes that the earth is a dynamic planet. Nothing about it is static, and none of its features will endure. In their observations of earth processes students are encouraged to ask where the earth materials came from and what happens to them afterward.

Flow of energy in the universe

This theme coordinates with the one before: changes in earth materials accompany all redistributions of energy. In their classroom activities students trace the path of energy from one part of a system to another. They also distinguish between potential and kinetic energy.

Conservation of mass and energy

Whether the topic is mountain building or the birth of a star, this course helps students account for the constant sum of matter and energy. Each investigation challenges students to discover at what point energy was changed from one form to another.

The earth-moon system

Even in an introductory text many observations in earth science are explained best by considering the earth and moon as a double planet system. Students who go on to more advanced science courses will not have to unlearn outmoded theories concerning tides, for example. All students take away from this course a more accurate sense of the relationship between the earth and its partner in space.

Historical development

In line with its emphasis on science as inquiry, *Investigating the Earth* does not fail to mention that theories in earth science have been presented by men, remodeled by other men, and occasionally demolished by new information. Separate background features in each chapter highlight someone who made a special contribution to earth science. These biographical vignettes emphasize that discoveries are made by people, and that intuition and chance are an important part of the scientific method.

Features of the Text

Investigating the Earth is a combined textbook and laboratory manual. Laboratory investigations and classroom activities are integrated into the Text in a carefully planned sequence.

The twenty-two chapters are grouped around major concepts into five units. Each **chapter introduction** is an attention grabber, designed to stimulate students' interest and arouse curiosity about the contents of the chapter. **Division headings** set off the major portions of the chapter. **Thought and Discussion** questions appear at the close of each of these portions.

Numbered section titles further divide the chapter and form a running outline of the chapter's contents. **Laboratory investigations** appear as separately numbered sections. These section numbers are used for cross-reference within the Text and in the Teacher's Guide. An **Action** within a section describes a way students can explore or illustrate the subject being discussed. Biographical and historical **vignettes** that highlight people and events in earth science appear frequently throughout the book.

At the end of each chapter there is a discussion of some of the **Unsolved Problems** related to material in the chapter. This section emphasizes uncertainty and controversy. In the classroom it provides topics for open-ended discussion. Sometimes, in addition, the Text suggests special activities in this section.

The **Chapter Review** summarizes the significant concepts and principles presented in the chapter. It is followed by **Questions and Problems** grouped by level of difficulty. **Suggested readings** is a short list of supplementary books for students who want to read more or extend their investigations.

Features of the Teacher's Guide

The Teacher's Guide has been designed to assist you in teaching *Investigating the Earth*. The backbone of each chapter in the Guide is the list of **Chapter Objectives.** These objectives are stated as behavior goals. You can use them as a basis for lesson plans and evaluation of student achievement. **Teaching the Chapter** gives a brief overview of the content and summarizes how the chapter contributes to the development

of the unit. It also contains the suggested time required.

Section Notes correspond to the numbered sections of the Text. The notes describe day-to-day operation in the classroom and offer practical help in presenting the material. The notes include demonstrations you can use, class activities, sources of enrichment materials, and aids to discussion of the Text.

The **Section Notes** that serve as guides to investigations give immediate, practical help in the conduct of each exercise:

Advance Preparation lists any specific tasks that must be completed before the investigation. Of course, you always should try the investigation yourself first with the equipment students will be using.

Time Requirements estimates the time needed for the lab and the discussions that introduce and follow it. These estimates are based on 45-minute periods.

Materials specifies the ideal student grouping for the investigation and lists what each group will need.

Special Notes (when needed) point out any unusual pitfalls the lab contains and cautions it requires.

Pre-lab Discussion suggests specific ways you can introduce the problem students will investigate.

Notes on Procedure contains procedural helps for the teacher.

Range of Results gives you an idea of what results you may expect for each investigation. It includes samples of charts, diagrams, and calculations by students. Since many investigations are open-ended, the range of results can be very great.

Post-lab Discussion is a guide to help you direct the students' analyses of the investigation. Discussion questions are suggested as models, but you should add your own, too.

Answers to Questions asked in the Text are included here. While these sample answers will be useful, students often will come up with acceptable alternatives.

Suggested Additional Investigations contains suggestions for the entire class or for students who wish to pursue a topic further.

Answers to Thought and Discussion questions appear in the same order and location as they do in the Text. For your convenience, each question is repeated before the answer.

The last section in each chapter is a **Discussion of Unsolved Problems.** It contains background information and ideas you can use to lead a discussion. **Answers to Questions and Problems** and **Supplementary Materials** conclude each chapter. The annotated bibliography lists reference books, films, and other aids useful in teaching the chapter.

Teaching *Investigating the Earth*

Investigating the Earth is an exciting, challenging course to teach. It involves a variety of methods of presentation: discussion, demonstration, laboratory investigation, and audio-visual techniques. Make notes in this Guide as you teach. Add your own pages to record, for example, improvisations successful with your classes and topics where students had many questions.

In all the classwork, it is vital to maintain a spirit of inquiry. Students should be active participants in this course. Your task is to encourage them to observe, measure, interpret and discuss the problem at hand. During investigations students should be free to move around the classroom, to use equipment, consult a reference text, or confer with a laboratory partner. Students should present evidence for their observations and freely challenge the interpretations of others.

The Text version of the laboratory investigations is intentionally brief to give students an opportunity to inquire, to discover, and to innovate. Students may devise ways to expand an activity to investigate a problem further. Extra detail on procedures and results is in the Guide. Use this help in a manner that will not rob students of the opportunity to investigate on their own.

Encourage students to describe the aims and results of the investigations in their own words. Naming and classifying are not emphasized in *Investigating the Earth*. The emphasis is on developing the major concepts and practicing the various scientific strategies in the investigations.

The Guide will help you in your primary role of helping students synthesize their experiences into a meaningful whole.

Auxiliary Materials

As a convenience for teachers, laboratory kits have been developed for many of the investigations. Substitutions for kit materials are listed for teachers who want to assemble their own apparatus. A complete listing of equipment and supplies is given in Guide Appendix C.

A variety of auxiliary materials — pamphlets, audiovisual aids, and field guides — were developed to supplement this course. These materials are listed in Guide Appendix D.

A wide range of reference and enrichment materials is given in the Supplementary Materials section of each Guide Chapter.

In addition to the textbooks, Teacher's Guide, and laboratory kits, individual student *Laboratory Supplements* and *Progress Tests* are available through Houghton Mifflin Company's regional sales offices.

Planning Ahead

You will need to order the materials listed below at the beginning of the school year to be sure they are on hand when you need them.

1. Epicenter Cards for the Earthquake Watch come from the Environmental Science Services Administration (ESSA). Order them on your school letterhead stationery using the sample letter below as a model.

   Director, Coast and Geodetic Survey
   Environmental Science Services Administration
   Coast and Geodetic Survey
   Rockville, Maryland 20852

   Attention: Seismology Division

   Dear Sir:

   Please place my name on the mailing list to receive the Preliminary Determination of Epicenter Cards. We will be using them during the next four months in a study of earthquakes as part of our earth science course.

   Sincerely,

   (Name)
   (Title)

2. For the Weather Watch you will need a variety of U.S. Weather Bureau publications available from:

   Superintendent of Documents
   U.S. Government Printing Office,
   Washington, D.C. 20402

   Order: (a) Cloud Code Chart No. 30.22C-62/2/958, $0.10
   (b) Instructions for Climatological Observers, Circular B, No. C 30-4:B/962, $0.50
   (c) Daily Weather Map, subscription rate $9.00 per year: minimum of three months for $2.40

Teaching Schedule

This suggested calendar will provide a guideline for you in planning a teaching schedule for the academic year. The calendar is designed for a class that meets five days a week for about 45 minutes. It assumes that the students do not have severe learning disabilities.

The suggested teaching times do not include class time for testing, films, continuing investigations, or special projects.

unit one

The Dynamic Earth

1. The Earth and Moon in Space

Chapter Objectives

After completing the chapter, students should be able to:

1. Explain how the size of the earth can be measured.
2. Identify the assumptions and inferences made in determining the circumference and volume of the earth.
3. Cite proofs that the earth and moon each rotate on an axis and revolve around the sun.
4. Explain the causes of the seasons.
5. Explain what causes the tides.
6. Demonstrate how phases and eclipses of the moon occur.
7. List similarities and differences between the moon and the earth.

Teaching the Chapter

The spirit of *Investigating the Earth* is introduced to students in this chapter. It is an integral part of the approach that students investigate for themselves the concepts and topics to be studied. In the investigations all students may not want to investigate the same properties or use the same techniques. *Encourage independent investigation.* A variety of techniques, data, and conclusions can then be compared during the post-lab discussions.

In this chapter, students will investigate the size of the earth and the effects of its movements. Students also begin collecting data for two long-term investigations that will continue beyond the end of this chapter. Students will be less likely to treat these observations as busywork if, from the outset, they know what judgments they will have to make from the data.

The concept of an earth-moon system may be new to most students, since they have been taught to think of the earth and moon individually. The interaction of these two bodies to produce effects such as tides, phases, and orbits is emphasized throughout the chapter.

In Chapter 2 students will investigate and compare the materials that compose the earth and moon.

Suggested time required

About eight to ten days will be required to complete the investigations and discuss the topics in this chapter.

Section Notes

Introduction

What do your students include when they think about their environment? What do they leave out? The activity that opens this chapter gets the students to consider how they think they fit in the world . . . and how big their world is. They can compare their answers to the Text's claim that the entire planet is home. Encourage students to talk about their lists and their sense of belonging. Make a list yourself if you like, but be sure students don't think that someone has the right answer.

The next time the class meets they will be investigating how to measure the earth, so be sure to assign at least the first two sections in the Text for reading.

1–1
The view from space

The concept of a double planet may be difficult for students to understand. Looking at the two from an observation point not on either one may help to make this proposal more acceptable. Obviously they must do this vicariously by looking at photos of the double planet system. Ask students to interpret what they see in the photos of the earth and moon. What differences and similarities do they see in each? Does each have an atmosphere? Are the surface features the same? Which are the day and night areas? Use questions like these to get students to participate in the discussion.

Be sure to ask students why they gave a certain response. If a student has a valid reason for an answer, it should be accepted. Students soon realize that their responses must be supported by observation and that there can be more than one valid answer. This attitude should be developed throughout the program.

1–2
Measuring the earth

Advance preparation

This investigation was written for a 20-centimeter (8-inch) globe using a scale of 1 centimeter:625 kilometers. However, you can use any other size, provided you make proper scale conversions.

If a spotlight, projector, or some other artificial light source must be substituted for sunlight, test the source to be certain that it is strong enough to cast a distinct shadow anywhere in the classroom. The room should be dark except for the light from the artificial sun.

Time requirements

Pre-lab	10–15 minutes
Lab	15 minutes
Post-lab	10–15 minutes

Materials

The following materials will be needed for each group of two students:

- Globe, 20-cm diameter, from Globe Kit
- Flexible ruler from Globe Kit
- Rods or toothpicks up to 10 cm long, 2
- Clay or suction cups to attach rods to globe
- Protractor
- Cardboard or stiff paper, 20 cm square
- String, 100 cm
- Light source, such as a projector or a 200-watt bulb with a reflector

Special notes

If the sun does not shine on the day the investigation is scheduled, be prepared to reschedule the investigation or to use the artificial light source. Experience has shown that this investigation is far more effective when done in sunlight. Without sunlight, it will be more difficult for the students to see the shadow clearly and to measure the angle accurately.

If students have not dealt with alternate interior angles in math class, you might have them either draw a pair of parallel lines or use lined notebook paper. Next, have them draw several diagonals across the parallel lines. They can then measure the opposite interior angles with a protractor and see for themselves that they are always equal. Another method they might use is to cut out one pair of angles and superimpose it on the other.

Pre-lab discussion

A way to get students to appreciate the simplicity of Eratosthenes' method is to compare it to other ways the earth's circumference might be measured. Your class probably can suggest other ways to measure the earth: using planes, satellites, or a very long string. Try to identify all the elements of each method, and talk about whether they could have been used a couple of thousand years ago. For instance, a satellite would not have been available to Eratosthenes.

You may wish to show the film *Measuring in Astronomy: How Big, How Far* at this point. (See Supplementary Materials.)

Notes on procedure

Although angle a of the vertical stick in the schoolyard should be measured around noon, an hour either way will make little difference. You may wish to have students from early morning and midafternoon classes assemble at noon to make the measurement. Take the class to a level place so that the vertical stick will be an exten-

sion of the earth's radius. Check by using a plumb line. It is also essential that the sticks mounted on the globes be extensions of radii. If suction cups are used to hold the sticks, this will not be a problem. If you use clay or wax, devise a means of checking to see that the sticks are perpendicular to the surface.

Have students set up the globes as shown in Guide Figure 1–1. The trickiest part of this procedure is measuring angle a. By rotating the protractor slightly the students can get a shadow zone as shown in Guide Figure 1–1. Do not give any instructions beyond those in the Text.

After students have determined the circumference of the globe, they use a similar procedure in order to calculate the circumference of the earth. They can measure the angle directly, but you will have to supply the distance d from your location to the point on the earth where a vertical stick would cast no shadow. To do this, determine the angle students will measure and use the formula in the Text to calculate the d that will give a D equal to the earth's circumference. You may determine angle a either by measuring it or by adding the number of degrees the sun is south of the equator to your latitude. (From March 21 to September 23 the sun will be north of the equator and you'll have to subtract the number of degrees from your latitude.) The sun's declination may be found by using the analemma in Guide Figure 1–2.

Students calculate their percentage of error in this way: First find the difference between the dimensions of the earth given in the Text and the value obtained in the investigation. Then divide that difference by the actual dimensions. The result is the percentage of error.

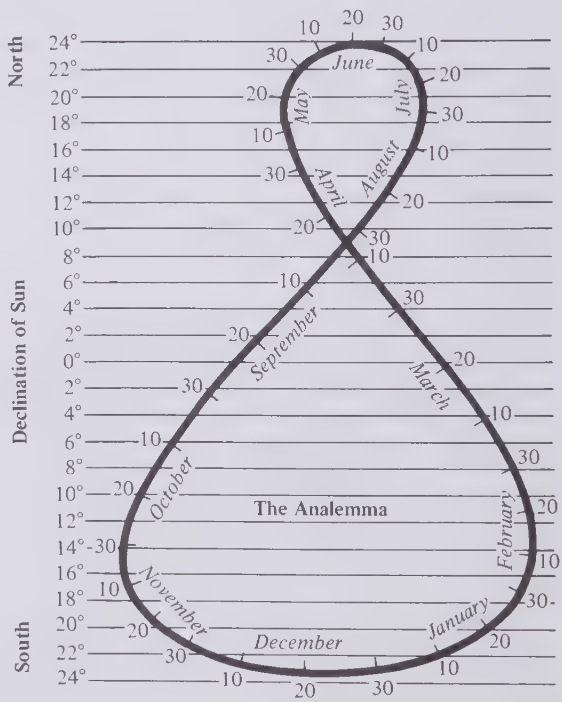
Range of results

On the globe the difference between the calculated value of D and the value obtained by direct measurement with the ruler or string can be as low as one per cent, especially if the investigation is carried out in bright sunshine. Any answer with less than ten per cent error, however, should be considered outstanding. If the investigation is done with artificial light, the difference will probably be greater because of the closeness of the light source to the globes.

For the circumference of the earth itself, the results will vary with the time of day. Since you

Guide Figure 1–1
How to determine angle a from the shadow on a globe in sunlight.

Guide Figure 1–2
Find the date on the analemma. Then read the declination of the sun on the left-hand scale.



calculated d for noon, any reading of angle a not taken at noon will yield a result smaller than the actual circumference. This makes an excellent point to discuss, as it ties in with Investigation 1–7, which deals with the apparent motion of the sun.

Post-lab discussion

Begin by comparing results. Students who are more than 20 per cent off the true value should be asked to review their procedure briefly. Possible sources of error may include misinterpretation of directions or mistakes in procedures or computations.

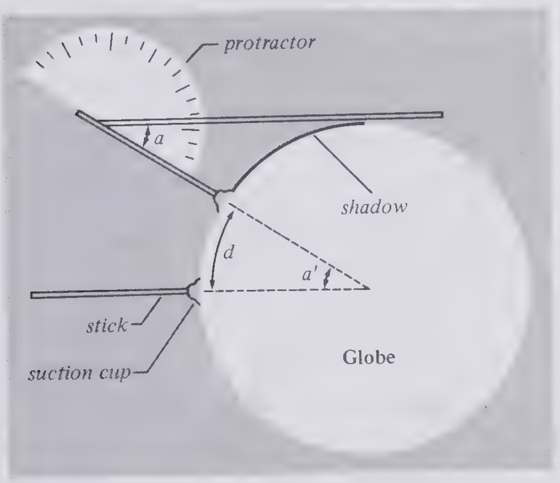
Next, through discussion, determine if students have been able to make the transfer mentally from their globe model to the actual dimensions of the earth's circumference. Briefly review the similarities and differences between the investigation done by the students and the determination made by Eratosthenes.

The accuracy of the measurements and calculations is *not* as important as the student's understanding and awareness of how the elements of the formula apply to the earth. You can discuss the range of the variation caused by each source of error if time permits.

1–3
How do you know that the earth rotates?
1–4
Proving that the earth rotates

These two sections can be discussed at the same time.

Guide Figure 1–3
Using the stick's shadow to find the position of a line parallel to the sun's rays.



You might have two students act out Figure 1–5.

The question at the end of Section 1–3 is a good place to introduce students to the difficulty of separating causes from effects in scientific investigations. Some of the proofs of earth's rotation students are likely to suggest—day and night, and the apparent movement of stars, for example—were once used as proof that the *earth* was the fixed center of the universe. Later chapters will cover the Coriolis effect, the equatorial bulge, and other evidence used to prove the earth rotates.

You can simulate the Foucault pendulum demonstration by swinging a washer (or some other weight) on a string while someone slowly turns a globe beneath it. If you swing the weight by hand you can show that the pendulum does not change direction over the equator. Perhaps a student would like to use the setup to show why the pendulum in Paris took more than 24 hours to rotate 360°.

1–5
The earth revolves around the sun.
1–6
The seasons

You might have a group of students use a portable recorder to tape the sound of a car passing with the horn blowing. They might be able to record other sounds as well. Play the recording in class and discuss how the Doppler effect is explained by Figure 1–9. You also can find excellent examples of the Doppler effect on sound effects records.

One way to emphasize how the seasons result from the tipping of the earth's poles is to ask students to describe how the earth's climate would be different if the axis weren't tipped. Or, what would it be like if the tilt were doubled?

1–7
Investigating the sun's path — Sun Watch

Advance preparation

If the time is limited to 45 minutes or less during the first period that you do this investigation, you may find it helpful to have several students help you construct the setups in advance. This would allow you more time for data collection.

Time requirements

Pre-lab	10 minutes with equipment set up beforehand
Lab	5–10 minutes each time readings are taken
Post-lab	10 minutes for first day's readings 10 minutes for comparing different days

Materials

The following equipment will be needed for each group of two students:

- Transparent plastic hemisphere from Globe Kit
- External protractor to fit hemisphere
- Marking crayon or pen
- Cardboard baseboard for hemisphere, 30 cm × 30 cm
- Masking tape

Pre-lab discussion

Explain that this investigation requires taking readings several times throughout the day. Go over the plotting procedure and emphasize the necessity for orienting the baseboard the same way for successive readings.

Notes on procedure

Many teachers have found success by numbering each setup and having students in successive periods place their hemisphere in the same position as the group in the previous class. This is suggested for those teachers who have three or more classes of shorter duration.

If you have a long lab period, you may take two readings about one hour apart.

Using the procedure illustrated in Guide Figure 1–4, construct and mark a true north-south line on the school ground. To do this, extend the line of the sun's path to both horizons. Connecting these end points by a straight line while keeping the hemisphere in its proper recording position will give a true east-west line. A perpendicular drawn to this east-west line will be a north-south line. You can mark it with a crayon on the pavement or with two roofing nails driven into a macadam playground surface.

The sun's position should be plotted as shown in Figure 1–3. The first sighting can be made before school. The others can be made at midmorning, noon, midafternoon, and after school.

Select one of the hemispheres as a *master sphere* for the class and store it in a safe place. On the master sphere mark the readings taken on the other dates. If these dates occur on weekends, holidays, or cloudy days, take readings as close to the date as possible.

Range of results

Typical results are indicated in Guide Figures 1–4 and 1–5.

Post-lab discussion

These questions are examples of ones you might ask students to answer with the aid of their globes. Is the sun directly overhead at noon? Since the observer is considered to be exactly at the center of the plastic hemisphere, directly overhead would be the top of the hemisphere. The sun's path will not pass over the top of the hemisphere for any latitude within the continental United States. Between the Tropic of Cancer and the Tropic of Capricorn the noon sun will be overhead on two days each year.

Does the sun rise in the east and set in the west? Unless the observations were made at an equinox, the sun will always rise and set north or south of a true east-west line. Use a diagram or model to help students see the connection between the earth's rotation and revolution and the apparent motion of the sun.

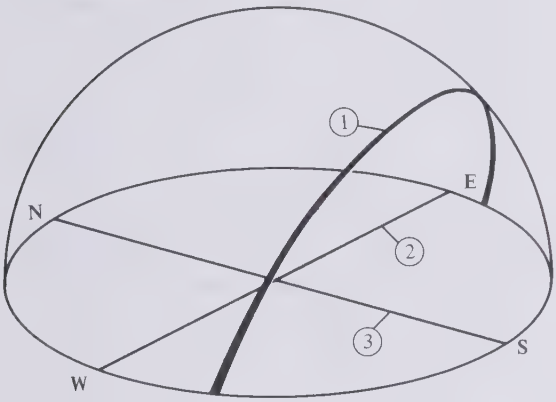
Answers to thought and discussion

1. If our skies were always cloudy, do you think we could prove that the earth rotates? Do you think we could prove it was round? **Answer** A Foucault pendulum still would provide evidence that the earth rotates. Sailors and pilots still could travel around the earth. Ships still would disappear over the horizon hull first, and reappear mast (or smokestack) first. Students may think of other evidence.
2. Does it seem strange to you that the barycenter is *inside* the earth? Since the earth is turning on its axis, does this mean that at one time of day the barycenter is under the Atantic Ocean, and 12 hours later under the Pacific? **Answer** The barycenter is a balance point computed from the masses of the earth and moon, and the distance between their centers. Since the earth is much larger than

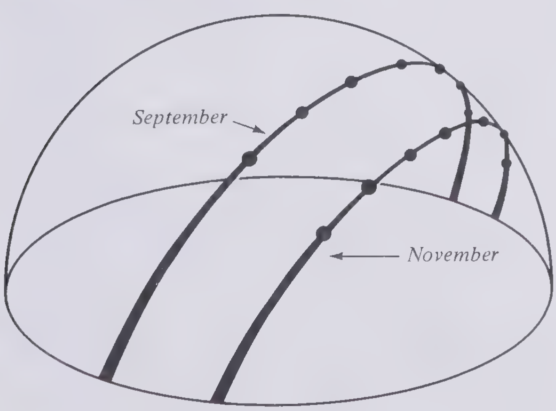
the moon the barycenter turns out to be about 1600 kilometers below the surface of the earth. It is not a fixed point. It moves on a fixed orbit at a certain depth within the earth. Its position relative to an observer on the earth constantly changes.

3. How could a person be thirteen years old and yet have lived through sixteen summers? **Answer** The thirteen-year-old has traveled a lot. Three times, when it was winter in the Northern Hemisphere, the person lived in the Southern Hemisphere, where it was summer.
4. What daily paths of the sun do you think you would draw if you conducted your Sun Watch at the equator? At the North Pole? Would a person at the North Pole ever see a sunset? **Answer** At the equator the sun always rises and sets perpendicular to the horizon. On the equinoxes the sun's path passes through the zenith. Summers it follows a parallel path a little to the north; winters it goes a little south of the zenith. At the North Pole the sun's path is almost parallel to the horizon. Sunrises and sunsets occur, but at rather odd times by the clock. Some days in summer the sun never sets at all. And in deepest winter it will not rise.

Guide Figure 1–4
Extend line 1 through the recorded points to the horizon of the plastic hemisphere. On the baseboard connect the east and west points to form line 2, a true east-west line. Draw line 3 perpendicular to line 2 to construct a north-south line.



Guide Figure 1–5
Plotting the sun's path on the plastic hemisphere for two different dates.



5. Can you figure out why the Foucault pendulum will not rotate at the equator? **Answer** At the equator the pendulum's support rotates with the earth every day. Since the pendulum and the observer rotate together, there is no change in its apparent direction. At the pole the pendulum's suspension point does not rotate while the earth and the observer turn beneath it. This relationship is easier for most people to visualize with the help of a model, such as Figure 1–7.
6. From the earth's speed around the sun (30 kilometers per second) can you figure out how far we are from the sun? Hint: There are about 31 million seconds in a year. **Answer**
   30 km/sec × 31 million sec/year
   = a circumference of 930 million km/year
   $2\pi r = 930$ million km
   r = approximately 148 million kilometers
7. What sort of seasons would there be if the earth's axis were tipped 90 degrees instead of only 23½ degrees? **Answer** The seasons would be more extreme everywhere. Summers would be much hotter at the poles. On June 21 the sun would shine directly on the North Pole. Six months later it would be directly above the South Pole. The equator would have winters much colder than it does now. No place would be the same temperature all year.

1–8 The moon in motion
1–9 The tides

Many teachers have been successful when the double planet concept is used consistently to describe the motions of both earth and moon.

Three-dimensional models of the earth and moon will be especially helpful when students are trying to figure out the motions of the moon. Acting out the motions with models forces students to have a perspective from outside the earth-moon system. Students are more likely to be confused if they try to visualize the motions from a point on earth.

One way to begin a discussion of tides, even if no ocean is close enough nearby to observe, is to look up predicted times of high tides in an almanac. Some questions you might discuss with your class are: Do the times vary from place to place along a coastline? Can you match the tides with the phase of the moon? Do high tides occur at the same time daily? Do tides occur only in water? Could there be "land" tides?

1–10
Phases of the moon

Students can best understand how positions of the moon, earth and sun cause phases of the moon when they have to reproduce these positions. Using a light source and a sphere in a darkened classroom, have students position themselves so that they can observe the new moon, first quarter, full moon, and last quarter.

1–11
Moon Watch

This long-term activity requires students to observe a part of the environment that is slowly but constantly changing. Not all students will become deeply involved over the suggested two months. However, you should find that most students try to find answers to the questions.

Some students are surprised to find that the moon is not visible on every clear night and that it does not rise or set at the same time daily. Many will notice the moon in the daytime for the first time.

Guide Figure 1–6, the Moon Watch form, can serve as a model that students modify to fit their own needs. You could also make a stock of forms available during the activity. Encourage students to carry forms in wallets and purses throughout the observation period to simplify the recording process.

Answers to questions

1. When you see the moon on your way to school, what phase is it in? What phase is it in on your way home? Does the phase of the moon depend on the time you can see it in the sky? **Answer** The moon is near last quarter when you see it in the morning. It is in first quarter when you see it in the afternoon. The time that the moon is seen depends on the phase that it's in. Last quarter phase, for instance, cannot be observed during the afternoon or early evening.
2. Does the moon rise earlier or later each day? **Answer** The moon rises about 50 minutes later each day.
3. Does the moon move westward or eastward with respect to the stars? **Answer** Eastward.
4. How many days elapsed between full moons? **Answer** 29–30 days between full moons.

Guide Figure 1–6
Sample Moon Watch form.

Moon Watch Data			Name:		
Date	*Time*	*Is the moon visible?*	*Direction (E, SE, and so on)*	*Height (horizon is 0°, overhead is 90°)*	*Moon's phase and positions of any nearby stars*

5. How many days elapse before the moon is seen among the same stars again? **Answer** 27–28 days for the moon to reappear in the same constellation.
6. When the crescent moon is seen in the western part of the sky, is it just before or just after the new moon? **Answer** A crescent moon would be in the western part of the sky just *after* the new moon.
7. Can the crescent moon ever be seen at midnight? **Answer** Never in our latitudes. It would always be below the horizon by then. If you were near the poles, you could see the crescent moon occasionally at that time.
8. Do the points of the crescent point toward or away from the sun? **Answer** The points of the crescent always point away from the sun.
9. If one evening while sitting in a chair, you see the moon through a window, what time the next night would you have to sit in exactly the same place to see the moon in about the same position in the sky? **Answer** About 50 minutes later.
10. What time does the first-quarter moon rise? **Answer** The first-quarter moon will rise near midday.

1–12
The lunar orbit

If students have difficulty understanding the characteristics of an ellipse, have them make several different ones using the method shown in Figure 1–20. Have students describe how the motion of an object with an elliptical orbit differs from that of one with a circular orbit, for instance, an object attached to a string and twirled in a circle.

The motion of a baton, with both the heavy and the light end revolving around a center of mass, could be used as an analogy for the earth-moon orbit. However, in this analogy the two bodies are always the same distance from each other, which is not the case for the earth-moon system.

1–13
Eclipses

Students can demonstrate eclipses in a darkened room by using a bright light and two spheres. Have them partially and completely eclipse each sphere.

Be certain to point out the danger of staring directly at the sun during a total eclipse, even through dark glasses. Any reference on eclipses, or an encyclopedia, will describe alternate ways to observe the sun. The simplest method is to project the sun's image through a pinhole in a card.

1–14
Gravity

You can have students calculate their weight on the moon, where the force of gravity is one sixth that of the earth. Class discussion might consider some of the ways that lunar gravity determined how Apollo astronauts moved on the moon. Would the lunar rover be suitable for similar work on earth? If not, what would have to be changed?

Have the students make a list of the ways that gravity affects their lives. Many points can be mentioned, such as the composition of the atmosphere, erosion, and the necessary strength of materials. Some students may suggest that the human body needs gravity to function properly.

Answers to thought and discussion

1. Many people, including news commentators, confuse the hidden side of the moon with the dark side. How would you explain the difference to them? **Answer** We never see the moon's hidden side from earth. The moon rotates once each time it revolves around the earth, so the same side always faces us. Which half of the moon is dark depends upon where the sun is. We can see part of the dark side anytime except at full moon.
2. Do you think astronauts on the way to Mars could ever see the full moon? **Answer** No, not after they passed beyond the moon's orbit.
3. Have you ever seen a total solar eclipse? A partial eclipse? Describe your experience to the rest of the class. What is the main difference in appearance between a total and a partial eclipse? Why do you have a better chance of seeing a partial eclipse of the sun? **Answer** In a partial solar eclipse, not all of the sun is covered. The sun is so bright that

even a small portion of its disc will make a lot of sunshine. There still will be daylight shadows, and a nearly normal-looking sky. Only during a total eclipse can you see the stars and the sun's corona. A partial eclipse can be seen from a much larger area of the earth than a total eclipse.

4. Why don't we have an eclipse of the sun every month? **Answer** The plane of the moon's orbit is tipped in relation to the earth's orbit around the sun. The three bodies don't line up very often. Some students may add that if the orbits were in the same plane there would be a solar eclipse every month. And, staggered by two weeks, there would also be a lunar eclipse every month.

Discussion of unsolved problems

There *is* a body of knowledge in science, but too often science is taught *as* a body of knowledge. This should not be so.The tiny world of scientific knowledge is surrounded by a universe of ignorance. The most fascinating learning for anyone is learning something no one ever knew before. This book, like most texts in science, is built around knowledge. Be sure to point out to the students that the small sections devoted to "unsolved problems" do not do justice to the universe of ignorance.

Discussing unsolved problems may seem both unnecessary and undesirable because there are no answers. However, in their first experience with science, students should become aware that it is unfinished business. Some of your students may very well make a career in science helping to solve one of the problems mentioned here.

You can use the unsolved problems mentioned in the Text as a starting point of discussions with the students. There is no reason why you couldn't use a current news item instead. Another way you might handle this section is to invite someone to speak to your class on a topic from the chapter, careers in earth science, or a local land-use problem, to name a few possible topics.

Answers to questions and problems

A

1. What is the difference between rotation and revolution? **Answer** Rotation is the spinning of a body around its own axis. Revolution is the orbital movement of a body around another point or object, as in the case of the earth's yearly revolution around the sun.
2. What evidence can you give that the earth rotates? **Answer** The simplest evidence is the demonstration of the Foucault pendulum, which swings in the same plane while the earth turns beneath it. This proof won't work at the equator, however. See the answer to thought and discussion question 5.
3. What evidence can you give that the earth is revolving? **Answer** One proof is the Doppler effect on starlight.
4. What factors cause the seasons? **Answer** The tilt of its axis as the earth revolves around the sun produces variations in the distribution of solar energy.
5. If the earth's orbit around the sun and the moon's orbit around the earth were in the same plane, how often would eclipses occur? **Answer** There would be two eclipses every month. Solar and lunar eclipses would alternate every two weeks.

B

1. If you observe one particular star for an hour, in what direction will its position change in relation to you? **Answer** The star will move in an arc from east to west with Polaris very near the arc's center.
2. What causes the lag of the seasons? **Answer** The hydrosphere, atmosphere, and lithosphere store heat energy all summer. They release it in early winter, delaying the full effect of winter cold. In the spring, heat must be absorbed to warm up the earth before the temperature can match the season.
3. The sun is very much more massive than the moon. Why does the moon have the greater influence in producing tides on earth? **Answer** The moon is much closer than the sun.
4. How much of the moon's surface is visible at the new moon phase? at full moon? **Answer** At the exact new moon, none of the moon's surface can be seen. At full moon, half of the moon is visible.

C

1. How could you use the Doppler effect to prove that Mars is rotating? **Answer** Light

from the edge of Mars that is turning towards the earth will be shifted toward the blue. Light from the edge turning away from the earth will be shifted toward the red. This would not work if the axis of Mars' rotation were pointing straight away from the earth.

2. Is it possible to launch a satellite that would, when in orbit, always be located over the same spot on the earth's surface? **Answer** Yes. The satellite must revolve in the plane of the equator to stay above a single point. It also must go around the earth exactly once a day. You can demonstrate why these two requirements must be met with a globe and a marble.
3. Suppose the earth kept the same face toward the moon all the time. Would there be any tides? **Answer** There would not be tides as we know them. At each point on the coastline, the water level would stay at high tide, low tide, or some part in between, depending on whether it faced the moon or not. The only tide change would be in the small tides caused by the pull of the sun. (The sun is responsible for 2/5 of the size of the tides.)

Supplementary Materials

REFERENCE BOOKS

Hynek, J. Allen and Apfel, Necia. *Astronomy One*. W. A. Benjamin Company, Menlo Park, California, 1972.

Baker, Robert H. *When the Stars Come Out*. The Viking Press, New York, 1954.

Leonard, Jonathan, and Sagan, Carl. *The Planets*. Time-Life, Inc., New York, 1972.

Rey, Hans A. *Stars*. Houghton Mifflin Company, Boston, 1967.

Zim, Herbert S., and Baker, Robert H. *Stars*. Golden Press, New York, 1951. (Paperback)

PERIODICALS

Sky and Telescope
Science News

FILMS

Controversy over the Moon. 16 minutes, color. Encyclopaedia Britannica Educational Corp.

Eclipses of the Sun and Moon. 11 minutes, color. EBEC.

How We Know the Earth Moves. 11 minutes, color. Film Associates.

Measuring in Astronomy: How Big, How Far. 13 minutes, color. EBEC. This is an excellent treatment of Eratosthenes' approach to determining the circumference of the earth.

Moon. 11 minutes, black and white. EBEC.

Tides of the Oceans. 16 minutes, color. Bailey/Film Associates.

2. Earth and Moon Materials

Chapter Objectives

After completing this chapter, students should be able to:

1. Describe the significant similarities and differences between the lithosphere, hydrosphere, and atmosphere.
2. Classify various earth materials according to their origin.
3. Calculate densities, using accurate measurements of volume and mass.
4. Differentiate among atoms, elements, molecules, compounds, minerals, and rocks.
5. Explain how the characteristics of minerals give clues to their atomic structure.
6. Discuss the changes in minerals caused by their environments.
7. Compare the importance of various elements, such as oxygen, on the earth and the moon.

Teaching the Chapter

Chapter 1 challenged students to recognize the movements of the earth-moon system in space. This chapter focuses on the materials that make up the earth and moon. It opens with a general view of earth materials and then moves into specific concepts of atomic and molecular structure. The properties of water are emphasized, since they are a result of water's unique molecular structure.

The investigations give students experiences with various earth materials. Rock composition and texture are included along with the concepts of mass, volume, and density. Students discover the need for accurate measurements as they use the laboratory equipment.

Only a few rocks and minerals have been named, since naming itself is of little importance. Instead, the chapter concentrates on the properties of earth materials.

The chapter also discusses the chemical composition of earth materials and the abundance of elements in the earth's crust.

Suggested time required

It will take ten to twelve days to complete the investigations and discuss the topics in this chapter.

Section Notes

2–1
Comparing earth and moon materials
2–2
The origins of rocks

After the students are familiar with the terms igneous, sedimentary, and metamorphic, set out examples of the rocks listed in Guide Figure 2–1.

Ask students to hypothesize about the origin of the display specimens. Select a specimen and ask: Is this rock sedimentary, igneous, or metamorphic? What characteristics does this specimen have that helped you make your choice? Relate the characteristics of rocks to their origin.

Another discussion may result from the question: How would conditions that exist on the moon affect the formation of rocks there? The answers will be speculative, except for the obvious remark that it would be difficult for sedimentary rocks to form. However, many principles of rock formation on the earth will be brought out.

Show the film *Rocks That Originate Underground* when this section is discussed. (See Supplementary Materials.) It will be recommended

for showing again in Chapter 12 when students are better prepared to understand the more technical aspects.

Stress the idea that rocks are always undergoing change, even changing from one rock type to another. Limestone changes to marble and shale to slate. Show the class samples of coarse sandstone, banded gneiss, and granite for contrast. Point out the difference between the firm crystalline texture of the granite and the crumbly, fragmental nature of sandstone.

2–3
Investigating rocks and minerals

Advance preparation

Use small containers or beakers to keep the rock kits together. If you are not using the crushed granite from the Earth Materials Kit, you will need to crush enough rock to supply approximately 100 milliliters for each class. Sift it through a fine screen to remove the dust.

Time requirements

Pre-lab	5 minutes
Lab	30–45 minutes
Post-lab	10–15 minutes

Materials

The following materials will be needed by each group of two students:

Samples from the Earth Materials Kit:
- Granite. Coarse-grained, containing pink orthoclase, glassy quartz, and black biotite.
- Porphyry. Black hornblende crystals in a fine-grained mass.
- Quartz sandstone. Medium- to fine-grained, well-sorted quartz with few or no other visible components.
- Basalt. Dark-colored, fine-grained.
- Limestone. Light-colored, fine-grained.
- Gneiss. Coarse-grained, containing quartz, feldspar, and biotite.

Magnifier from Teacher's Kit
Teasing needle
Crushed granite from the Teacher's Kit, about 10 ml
Stereomicroscope (optional)

Special notes

This investigation is more important than it may appear at first glance. It allows the students to discover the difference between rocks and minerals without becoming too involved in new terminology. It provides the basis for further study of the composition and structure of rocks and minerals later in this course.

Avoid discussing rock names. Naming rocks is not important to this investigation and tends to obscure the basic objective of discovering ways to describe rocks.

Pre-lab discussion

Although rocks are common objects, challenge the students to look at them closely and to discover some things about them that they may not have noticed before. Pass out the rocks, teasing needles, and magnifiers. Explain how to use the magnifier. Be sure students do not use the magnifiers as scratch plates!

Ask students to examine each rock carefully, using the magnifier and teasing needle. Have them make a list of terms using their own words to describe how each rock looks.

In Part B, students will take a closer look at one of the rocks studied in Part A and describe its components in their own words.

Ask if the rock is made up of only one kind of material or of different kinds of material. If students say it consists of different kinds of material, how do they know this? Students are to keep these questions in mind as they examine the rock and the crushed material.

Guide Figure 2–1
The origin of some common rocks.

Rock	Origin
Sandstone	Sedimentary
Granite (coarse-grained)	Igneous
Shale	Sedimentary
Gneiss	Metamorphic
Limestone	Sedimentary
Basalt	Igneous
Rhyolite	Igneous
Schist	Metamorphic

Notes on procedure

Each student should make his own list of terms describing each rock.

Students may not realize it, but they will intuitively recognize that composition and texture determine the way rocks look. Part B of the investigation is based on this idea. If students mention this idea during the investigation or in the post-lab discussion, suggest that they can test it in Part B.

In Part B, tell students that they are to divide the rock pieces into piles of similar-looking materials. They should ignore any mixed grains or, if they wish, put them into a separate pile. Toothpicks, nails, or teasing needles can be used to manipulate and sort the crushed material. Grains will stick to a slightly moistened toothpick and will drop off when the toothpick is rubbed lightly against a desk surface.

If a group is having difficulty, you can ask questions to help them begin. For example: Are all of the materials the same color? Do any of the materials appear to have a consistent shape, or broken surfaces? After they have sorted out about a dozen grains of each material, students should see if they can discover similar material in the solid rock.

Although students have been asked to list terms that describe the way the materials in the rock look, they are actually making observations of mineral properties. Experience has shown that it is much more meaningful for the students to make up their own lists of mineral properties than to follow a set procedure.

Range of results

The following are examples of terms students frequently use to describe the rocks:

Granite. Grainy or granular, sharp edges, hard, rough, pink, black, speckled, white, sparkling.

Porphyry. Spotted or speckled, rough, grainy or granular, large grains, sparkling or shiny (in some places), heavy, chunky, black and white, salt and pepper, sharp edges, hard.

Quartz sandstone. Grainy or granular, sandy, layered, small-grained, light-colored, rounded edges, flat.

Basalt. Black or dark, dull, smooth surface, heavy, very small-grained, speckled, sharp edges.

Limestone. Smooth, no grains, chalky or powdery, dull, rounded edges, light-colored, white, creamy, easily scratched.

Gneiss. Layered or banded, granular, large- or medium-grained, sparkling, speckled, sharp edges, hard, rough, flaky, pink, black, white, rosy, different colors.

Some terms students suggest will have little value in describing rock features. Few of them will be found in a technical book on rocks. Nevertheless, many terms used by the students will reflect the two essential characteristics of any rock, *composition* and *texture*.

In the second part of the experiment there should be at least three piles of minerals: quartz, feldspar, and mica (biotite or muscovite). In addition, there may be minor amounts of other minerals such as hornblende. A brief description of each follows:

Quartz. Transparent, shiny, glassy, breaks irregularly.

Biotite (mica). Black, shiny, and flaky or platy.

Muscovite (mica). Transparent or yellowish, shiny, and flaky.

Feldspar. Rose, pink, milky, or colorless, chunky, breaks angularly.

Hornblende. Dull, greenish-black, elongated.

Students may think they see more components than really exist. This is because the same material may look different when viewed from another angle. For example, the end view of a piece of biotite is different from the top view. Also, cleavage and fracture surfaces of the same material commonly look different. Feldspar fracture surfaces appear similar to those of milky quartz, but the pearly-looking cleavage surfaces of the same feldspar grain will appear shiny where the light strikes them at the proper angle. Glassy or clear material such as quartz reflects colors from adjacent mineral grains in a solid rock. This may lead the students to think that there are several different-colored glassy minerals when there is only one.

Some of the minerals may be discolored with a coating of oxide. This will make it hard to recognize a given mineral.

Post-lab discussion

Use the chalkboard or an overhead transparency to record the students' terms for the materials they recognized in the rock. When all the terms

have been recorded, ask students to compare the terms used to describe the rocks in Part A with the terms used in Part B. It should be apparent that fewer terms were needed to describe the minerals in Part B.

Discussion probably will bring out that terms such as "rounded," "angular," "rough," "flat," and "dull" are not very useful in differentiating one rock from another. Terms that apply to only one part of a rock, such as "sparkling" or "white pieces," are also not very helpful. Certain terms and phrases, such as "layered," "banded," "grainy," "larger crystals in a fine background," leave little doubt about which rock is being described. These are *textural* terms that describe the way in which the individual parts of the rock are put together.

The descriptions given by the students involve color and shape. These two factors are sufficient to describe the differences in the minerals. Ask: Was this true for rocks? It was not true for rocks because most rocks are a mixture of materials. The appearance of a rock depends on the variety and relative amounts of the materials it contains.

Other questions you can ask are: Why did the pink material always break into blocks, the black material into flakes, and the glassy material irregularly?

You might use the contents of the Earth Materials Kit to illustrate the following points:

1. Rocks are commonly mixtures of different materials. The general term for these materials is *components*. The components of a rock are called *minerals*.
2. A mineral is a naturally occurring, crystalline, inorganic substance with physical and chemical properties that vary within limits.
3. Minerals are to rocks as letters are to words. A rock is made up of one or more minerals.
4. Every different kind of mineral has a name. Some mineral names such as quartz, biotite, and feldspar are used frequently throughout the Text.

This discussion should provide you with the opportunity to introduce the words *composition* and *texture*. The number and types of components, chiefly minerals, that a rock contains are its composition. The size, shape, and arrangement of mineral grains and other components in the rock are its texture.

If you wish to expand these ideas, see if the students can relate the composition and texture of a rock to its environment. Could composition and texture be related to the way rocks are classified as igneous, sedimentary, and metamorphic? Yes, they could be.

Answers to questions

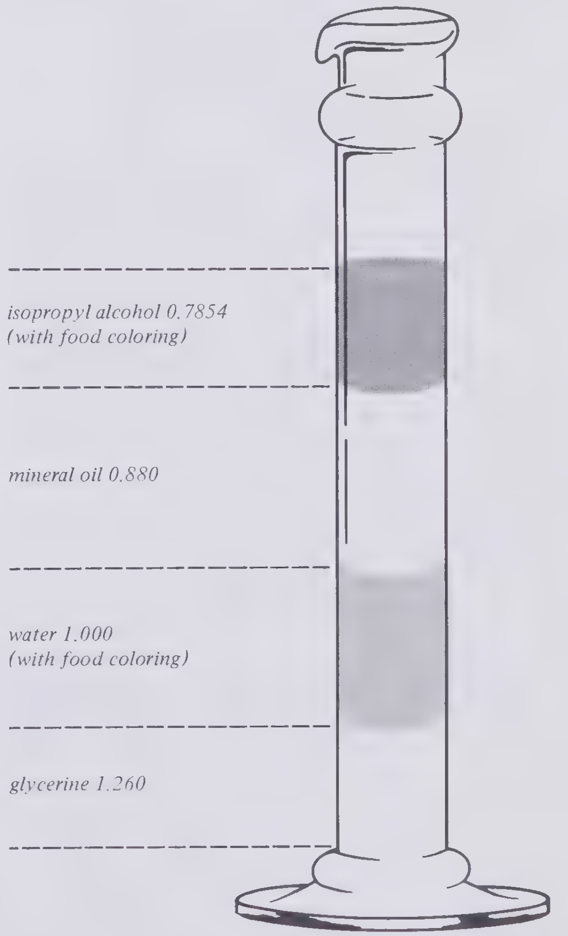
1. Students have been looking at minerals from the Earth Materials Kit, and rocks. Which was easier to describe? Why? **Answer** The piles of individual minerals were easier to describe than the rocks. Each pile consisted of only one kind of material, while the rocks were aggregates of different kinds of material.

2–4
Investigating mass, volume, and density

Advance preparation

Construct the liquid layers as shown in Guide Figure 2–2 at least a day early. Add vegetable

Guide Figure 2–2
The layering of liquids of various densities. Density values are given in grams per cubic centimeter.



coloring to alternate layers. Place the bottle or jar where the students will notice it as they come into class.

Have bottles for the opaque bottle demonstration filled, one with sand and the other with water. Cap them securely. Be sure that the bottles are filled completely so that shaking produces no sound.

On the day before the investigation, tell students to bring a pebble to class. *Give limiting dimensions* to be certain that the pebble will fit in the graduated cylinders the students will be using. Have some extra pebbles on hand for those students who forget to bring their own.

Breakage of glass cylinders can be minimized by fitting them with wide plastic or styrofoam collars near the lip.

Obtain ice cubes for Part B. Store the ice, water, and alcohol in a cooler. The water and alcohol can be in the beakers ready to distribute at the end of the demonstration, or you can first distribute the empty containers and then add the chilled liquids.

Try the demonstration and investigation yourself before class.

Time requirements

Pre-lab	5 minutes (Part A)
	10 minutes (Part B)
Lab	30–40 minutes (Part A)
	15–30 minutes (Part B)
Post-lab	20 minutes

Materials

The following materials will be needed for the demonstrations:

- Identical opaque bottles with caps: plastic shampoo bottles, liquid-soap bottles, or painted pop bottles
- Sand, enough to fill *completely* one of the bottles, labeled A
- Water, enough to fill *completely* the other bottle, labeled B
- Bottle or jar, tall and narrow, such as a 100 ml graduated cylinder or a large stuffed-olive jar
- Liquids, 10–20 ml of each: water, alcohol, glycerine, and oil (cooking oil, motor oil, or mineral oil)
- Food coloring

The following materials will be needed by each group of two students:

- Density Kit, or:
  - Aluminum bar, 8 × 3 × 1 cm
  - Aluminum cubes, 1 cm on a side
  - Steel ball, 1 cm
  - Glass ball, 1 cm
  - Ruler, 15 cm
- Oil-base modeling clay, approx. 50 g
- Triple beam balance
- Graduated cylinder, 100 ml
- Pebble
- Beakers, 250 ml, 2
- Water
- Isopropyl alcohol, approx. 250 ml
- Ice cubes, 3 or 4

Special notes

The smaller the object measured by immersion, the greater will be the percentage of error. Also, it will be more difficult to detect changes in volume. Use large ice cubes or large pieces of ice for better results.

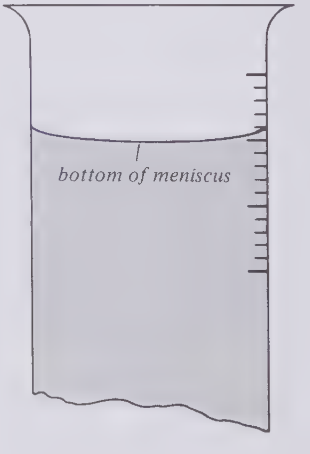
Do not substitute duplicating fluid or similar liquids for the alcohol unless you are certain that they are safe.

Not all alcohol has the same density; check to be sure the ice sinks. The alcohol can be reused as long as an ice cube sinks in it.

Pre-lab discussion

To get the students thinking about density, try asking: Which is heavier, a pound of feathers or a pound of lead? Then ask: Which is heavier, a bucket of feathers or a bucket of lead?

Guide Figure 2–3
The bottom of the meniscus is the correct place to read the volume of any liquid in a graduated cylinder.



Then give one opaque bottle to a student on one side of the room and the other to a student on the opposite side of the room. Ask the students to describe the bottles to each other. Because neither has any knowledge of how much the other's bottle weighs, they will find it difficult to make comparisons. Have the students exchange bottles. They will feel the difference immediately.

You might lead a discussion along the following lines: Are the bottles different? Yes, because one has heavier material in it. Are the bottles equal in volume? Yes. If the volume is equal, what property of the material is different? The mass is different. How can this difference be expressed? It can be expressed as a difference in the mass in a given volume, the density.

Point out that in comparing densities it is sometimes difficult to have containers with the same volume. For this reason, scientists have established a standard unit for volume, the liter. They do the same with length and mass.

The demonstration should last about 10 minutes.

Notes on procedure

Part A

Pass out the Density Kits and explain to students that they are going to determine the density of the aluminum bar. Students familiar with manipulating balances and reading graduated cylinders should be able to proceed with little direction from you. Students unfamiliar with using laboratory equipment will require some additional guidance. A guide to reading liquid levels is shown in Guide Figure 2–3.

You might assist inexperienced students by suggesting that they use the balance to measure mass and either the graduated cylinder or metric ruler to find volume. These measurements will allow them to calculate the density of the aluminum bar by the formula $D = M/V$.

After you have guided the students in determining the density of the aluminum bar, they should be ready to proceed independently. Students should make two density determinations on the clay, one with the entire sample and the other with about half the sample. In addition, each group should determine the density of at least one aluminum cube and one pebble.

You can suggest that students use a data table like the one in Guide Figure 2–4 to record their results.

If time allows, each group could determine the density of all objects in the kit. Most students can make four or five density determinations in one period. Have a few extra earth materials, such as a piece of granite or basalt for students who finish quickly.

Students can determine the volume of the spheres either by displacement or by using the formula $V = 4/3\pi r^3$. The diameter can be obtained by pressing a *wetted* sphere into clay. (A dry sphere will stick to the clay.) Or you can place the sphere between two aluminum cubes and measure the distance between them.

Students should use their data to answer the questions in Part A. The answer to question 4, which asks for the density of water, can be obtained by weighing a given volume of water. If the students understand density, this question should present little difficulty. It will alert them to the fact that liquids also have density. You might point out the liquid density demonstration jar as an example.

Encourage students to label carefully all recorded values so they will know which numbers to use in the formula. Since students commonly misplace the decimal point, you could suggest that partners talk over their results.

Guide Figure 2–4
Sample Data Table for Investigation 2–4

Object	Mass (grams)	Volume (cm^3)	Density ($grams/cm^3$)

Excessive handling of the clay, especially in warm weather, makes it more difficult to work with. It may develop air pockets that affect its density.

Part B

In Part B students design their own procedures for finding the density of an ice cube.

Obtaining the correct value for the density of ice is not nearly as important as giving the students an opportunity to solve a problem creatively. Most teachers have found that the open-ended style of investigation develops in students a deeper understanding of experimental science. First, the students feel genuinely involved. Second, they develop a greater sense of personal confidence than they do when more structured investigations are used.

Display two beakers containing equal amounts of clear liquids. One contains water and the other contains alcohol. *Do not tell students what the liquids are, or that the liquids are different.* Ask students what would happen if you were to put ice cubes in each liquid. Then place an ice cube in each beaker and ask the students to explain the results. The most typical comment is that the ice is strange or "funny." Interchange the ice cubes. Then the comment will probably be that you must have funny water. In what way is the water funny? The discussion should lead the students to realize that one liquid supports the ice the way water does and the other does not. The first liquid, then, probably *is* water and the second liquid is in some way different from water. Refer back to Figure 2–7 to see the difference in density between mercury and water.

The fact that ice floats in the water and not in the alcohol is the basis for establishing a relative density scale. Ask the students to list the three materials in order of increasing density. Alcohol, ice, and water is the correct order.

Now ask each group to find the density of an ice cube. Pass out the ice cubes, water, and alcohol and let the students begin.

Remember that the most important purpose of Part B is to have the students devise their own methods for determining the density of ice. Finding the correct density value is secondary.

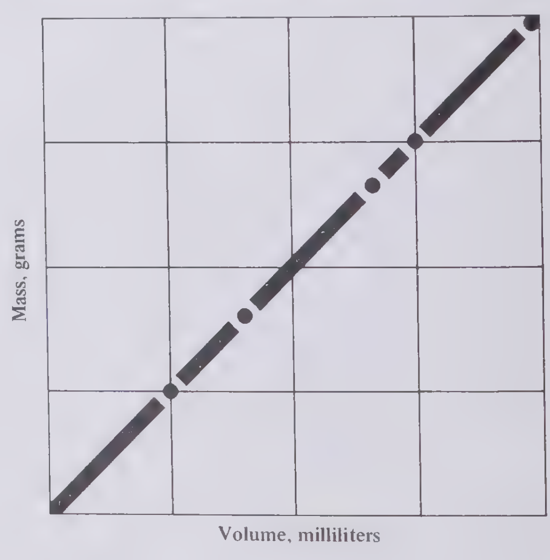
Students' responses will vary. Some students will start work immediately; others may think about the problem for a while. Some may appear completely frustrated by the assignment. Walk around the room and ask questions that will help the students review what they have learned about density. Frame your questions so that they lead the students to think about the type of information they really need, what they must do to get the data, and how to treat the data they have obtained. Encourage the students to try something, analyze their results, and then take another step. If they make a mistake, encourage them to decide for themselves what the mistake was and how they might correct it.

Be careful what you suggest about wasting alcohol. If you tell the students that they should always add water to alcohol to conserve alcohol, you will limit their chance to investigate the ice cube problem independently. If a student is wasting the alcohol by adding alcohol to water, you might ask him to analyze what he is doing to see if there is a better way.

Range of results

Density values obtained by students may vary as much as 20 per cent from the accepted value. The densities of the materials are as follows: aluminum 2.7 g/cm^3; glass 2.4 to 2.8 g/cm^3; steel 7.8 to 8.2 g/cm^3; clay 1.6 to 1.9 g/cm^3. The density of the pebbles generally will range between 2.5 and 3.0 depending on the type of rock. The density of water is 1.0 g/cm.^{3} A class average of pebble densities usually is near 2.8 g/cm^3, the average density of the earth's crust. If it isn't, students may be able to find out why. Perhaps they all got pebbles from the same place.

Guide Figure 2–5
Graph of mass against volume for clay. The slope of the curve gives the density.



Students have found at least six different methods of solving the ice-cube problem. These are listed below. There are probably several others as well.

1. Capitalizing on what they learned in Part A, students can measure the ice cube with the ruler and calculate its volume. They then obtain its mass with a balance, and determine its density. The result will be reasonably accurate, although the melting of the ice introduces some error.
2. Students can push the ice cube down into the water in a graduated cylinder and find the volume by displacement. The ice must be held just beneath the surface with a pin or a toothpick. The students then use the balance to obtain the mass and calculate the density of the ice.
3. Place the ice cube in a beaker of alcohol, as in the demonstration for Part B. The ice cube will sink. As water is added and the mixture stirred, the ice will begin to rise. When the density of the liquid is equal to the density of ice, the cube is suspended in the mixture. Students can determine the density of the liquid by measuring the volume and mass of the combined liquids and dividing the mass by the volume.
4. The relative displacement, or iceberg approach, can also be used. The students determine the dimensions of the cube edge, place the cube in water, and measure the length of the edge that is above the surface of the water. With these two values and the density of the water, students can set up a proportion that will give the density of ice. For example, if the ice cube were half submerged, the density of ice would be 0.5 g/cm^3.
5. Since the ice cube sinks in alcohol, students can measure the mass of the ice cube and then determine its volume by using the displacement procedure. Density is then computed in the usual way.
6. Students might look up or measure the density of alcohol, 0.8 g/cm^3. Since they know the density of water, they can estimate that the density of ice is somewhere between. The value for the density of ice should be about 0.9 g/cm^3. The density of ice may be decreased if air bubbles are trapped inside the cubes.

Students using $D = V/M$ will get a density value of 1.1 to 1.33 g/cm^3. Watch for misplaced decimal places when values such as 9.1 g/cm^3 are obtained.

Post-lab discussion

Students now have a common experience from which to develop a better understanding of density. Discuss the data needed to determine the density of solids or liquids. What problems did students encounter in obtaining data? How did they prevent problems from occurring, or solve them if they occurred?

In this situation you act as a catalyst, suggesting ideas but letting the students do the thinking and talking. This strategy is even more important for Part B than for Part A. In Part B the students have been on their own and you should recognize the variety of ideas that they have explored. In both parts the discussion can begin with having students report their values.

Record the values on the board, perhaps arranging them in relative order so that the range of values is evident. Ask for an analysis of the results. Is there a central tendency or common value that several groups obtained? Which values are too high or too low? Ask students from groups reporting unusually high or low values if they can explain their results.

It often happens that one or two groups will report a value carried to several decimal places, far beyond what is justified by the equipment used. This provides an opportunity to develop the idea of significant figures.

Answers to questions

Part A

1. What effect does the difference in the shape of a substance have on its density? Explain your answer. **Answer** Difference in shape has no effect because density is a property that is independent of shape.
2. What effect does the difference in the amount of the sample have on the density of the modeling clay? Explain your answer. **Answer** No effect. Density is a property of matter that is independent of amount.
3. Arrange your materials in order of decreasing density. **Answer** Steel, glass, aluminum, and clay. This list, of course, will depend on the objects each student used.

4. What is your calculated value for the density of water? **Answer** 1.0 g/cm^3, or 1.0 g/ml.

Part B

1. What is the approximate density of your ice cube? **Answer** The density of ice is approximately 0.9 g/cm^3.
2. Explain how you obtained this value. **Answer** The answer to this question will depend on the method the students use to determine the density of ice. Descriptions of several possibilities appear in Range of Results.
3. Sometimes ice cubes have holes or air spaces in them. Would these spaces affect the density of the ice cube? **Answer** Yes. There's often more or less to an ice cube than ice. Any other ingredient would affect the density.

SUGGESTED ADDITIONAL INVESTIGATIONS

Ask the students to devise methods for determining the densities of other objects that cannot be determined in a traditional way. What is the density of a person? (Suggestion: Does a person tend to sink or float in a swimming pool?) What is the density of a piece of chocolate cake? How would you determine the density of a balloon filled with helium? Does a balloon have the same density inside as the air outside? Interesting discussions and activities can result from ideas similar to these.

2–5 Elements

Show the students some crystals of quartz, pyrite, halite, and gypsum. (Quartz and halite are provided in the Earth Materials Kit.) Let them break some calcite and examine the fragments. Small rhombohedrons can be seen with a magnifier or microscope.

Demonstration There are many different ways to show crystal formation from molten material. For example, heat a small amount of thymol or salol on a glass slide or petri dish. Place the slide or dish on the desk top or on an overhead projector. Await the growth of crystals as the melt cools. Another way is to warm some mothball crystals gently in a glass petri dish until a thin liquid film forms on the bottom of the dish. Again place the petri dish on the overhead projector so that the class can watch the crystals form.

Your local telephone company may have a free educational kit on crystal growing. Limited numbers of kits are available for school use.

To be certain that students are familiar with some common elements, exhibit samples of iron, sulfur, tin, lead, carbon, and any other elements that are available. Pass the specimens around the class. Do not pass mercury around: it is too dangerous.

Point out that while most minerals are compounds, some are not. Naturally occurring elements are called *native elements*. Examples are silver, copper, and gold. If possible, try to have a piece of native copper on display for students to examine.

Action Periodic Charts in most chemistry texts list the elements and their states.

Answers to thought and discussion

1. What is the difference between a rock and a mineral? **Answer** Although a rock may be composed almost solely of grains of only one mineral, rocks are usually aggregates of more than one kind of mineral. Minerals, on the other hand, are inorganic, crystalline substances, composed of one or more elements. This generalization doesn't always hold. Coal, for instance, is a rock made of altered plant material. Obsidian is a natural glass.
2. Why is the moon considered a "dead planet"? **Answer** It appears to lack both a hydrosphere and an atmosphere. On the earth, energy interactions occur within these spheres. Also, energy is transferred between these spheres. Not much appears to happen to the solar energy reaching the moon, other than reflection. The moon is also referred to as dead because there is no evidence of sedimentary, metamorphic, or plutonic rocks. Lunar studies may lead to a revision of this idea.
3. What is the difference between an element and a compound? **Answer** Elements are substances which cannot be broken down into other substances. Compounds contain two or more elements.

4. What is the difference between a metamorphic rock, a sedimentary rock, and an igneous rock? **Answer** Metamorphic rocks are produced from other rocks that are subjected to great pressure, high temperature, and changes in their chemical environment. Sedimentary rocks are solidified deposits of the products of weathering. The sands and sediments can come from rock of any type. Other sedimentary rocks may form in a similar fashion from the remains of animals or plants. Igneous rocks form when molten materials from deep in the earth are pushed up into the earth's crust or poured out onto the earth's surface. There they cool and harden.

2–6 Atoms and their parts

Students already may be familiar with atomic structure. They may have some knowledge of such terms as atom, ion, isotope, molecule, and compound. It is important, however, to determine how well students understand these terms before proceeding further. Ask various students to define atoms, ions, or isotopes. Then concentrate on the ideas that are least familiar to the students.

The material in this section describes the components of an atom. It is not a good idea to try to picture an atom by making sketches, because the modern model of a nucleus surrounded by clouds of electrons cannot be shown in this way. To avoid this difficulty of representing atomic structure, you might show a film or filmstrip on atomic structure. Several are listed under Supplementary Materials.

The word *model* as used in this section may be new to the students. They may be familiar with one type of physical model from model trains, cars, or airplanes. In this course model means a representation of something. A *mental model* is an idea or hypothesis about something you cannot see. An example of a mental model is an idea about an atom's structure or the earth's interior. *Physical models* often are built to represent visible objects, like the earth's surface. They can also represent mental images like the mind's picture of the interior of the earth. A globe, for example, is a greatly reduced physical model of the earth.

2–7 The unusual water molecule

Ask students if they can think of any material other than water that exists naturally in all three states on the earth's surface. They will not be able to give a single example. Stress the fact that water has an atypical boiling point and unique properties as a solvent. Both characteristics are due to the dipolar nature of the water molecule. Some students might be interested in reporting in detail on water's properties and characteristics. (See pages 9 through 12 of *Water: The Mirror of Science*, listed in Supplementary Materials.)

When any salt is added to water, some of the properties of the water are changed. For example, its density is increased, its boiling point raised, and its freezing point is lowered. Therefore, ocean water does not freeze as readily as fresh water, and salt spread on icy roads melts the ice.

Demonstration If you wish, you can set up a demonstration to illustrate the two-to-one ratio of hydrogen to oxygen in the water molecule. Most scientific supply houses sell simplified electrolysis apparatus. Pages 133 through 134 of *A Sourcebook for the Physical Sciences* describe the construction of a homemade electrolysis apparatus. (See Supplementary Materials.)

Action Check the student models for the 105° bonding angle on the water molecule.

1. How could you arrange two nearby water molecules so they will attract each other? **Answer** The hydrogen end of one water molecule would be near the oxygen end of another water molecule.
2. Would water behave differently if the oxygen and hydrogen atoms were in a straight line? **Answer** Water would not be dipolar. Thus, its molecules would not attract each other. This would change such properties of water as its boiling point, surface tension, and its ability to act as a solvent.

Action A needle or razor blade will float on top of a quiet water surface because of surface tension. Several surface tension demonstrations are suggested on page 11 of *A Sourcebook for the Physical Sciences*. (See Supplementary Materials.)

2–8
Many minerals need special conditions to form.

Before starting the discussion, you might display samples of biotite, feldspar, calcite, quartz (clear, milky, or rose), galena, and pyrite. (Biotite is provided in the Teacher's Kit. Quartz and feldspar are both visible in the piece of coarse-grained granite provided in the Earth Materials Kit.) Specimens should show the properties of color, luster, fracture, and cleavage. Use large specimens or pass smaller ones around the class. Ask each student to examine the specimens and to report what he sees. As differences among mineral properties become apparent, students will be ready to discuss what gives a particular mineral its characteristics.

A student may be interested in reporting on local minerals. Optical and chemical properties of minerals may interest other students. Information on these topics can be found in any standard mineralogy text.

If possible, display pairs of minerals with the same chemical compositions but different properties, such as graphite and diamond (C) or pyrite and marcasite (FeS_2). You might ask the students how one element or compound could form more than one mineral. The answer is the varying conditions of temperature, pressure, acidity, or alkalinity at the time of mineral formation. For example, diamonds form only under very high pressure, so this condition must have existed in the crust when and where diamonds formed.

Different conditions thus will produce a different arrangement of the same atoms. Many common rock-forming minerals like mica, clay, and feldspar are composed of essentially the same chemical elements combined in different amounts and arrangements in response to different environments.

Demonstration Geologists use the occurrence of minerals to reconstruct past conditions. Illustrate this idea by heating some gypsum, $CaSO_4 \cdot 2H_2O$, to 150°C in a test tube. Water will collect in the upper part of the tube. When water is released, the gypsum has broken down to an anhydrite, $CaSO_4$, a different mineral. Hence, gypsum cannot form at or above 150°C.

2–9
Mineral properties and atomic structure

The chief function of this section is to extend the students' ability to relate the structure of a mineral to its properties. A good classroom activity is to compare slides or transparencies of silicate molecules to samples of silicates. You also could construct models of single-chain silicates and compare these models to real materials. These activities can show how silicate minerals are grouped according to the arrangement of their SiO_4 tetrahedrons.

Action Students may have trouble joining two tetrahedrons so that they share one oxygen atom. Let the students discover that the *one* oxygen atom common to both tetrahedrons is bonded to *two* silicon atoms. The silicons in the two tetrahedrons share the one oxygen atom. To make this model they must remove one oxygen atom, leaving a total of seven oxygen and two silicon atoms.

Let students experiment to find a logical way to unite tetrahedral units into chains. Try not to let this part of the action take longer than 10 minutes. To construct the single chain silicate, lay the string of spheres on the table and place the doubles in the spaces (notches) between the spheres in the string (Guide Figure 2–6). Arrange them so that three doubles are in alternating notches on one side of the string and the two other doubles are in the remaining notches on the other side of the string. Join the doubles to the string with pipe cleaners so the model looks like Guide Figure 2–7.

If a student would like to investigate additional silicate structures, you can carry the model work further.

Each oxygen atom at the corner of an SiO_4 tetrahedron has one extra negative charge. A positively charged ion of the proper size can fit between the SiO_4 units without strain. Iron and magnesium fill this requirement. They are surrounded by six corner oxygens and form octahedrons. An oxygen atom may become part of an SiO_4 tetrahedron and of an iron or magnesium octahedron as well. All of the atoms fit properly and the charges are balanced. Such a mineral is called an *olivine*. The olivine series may contain iron and magnesium in any proportion. The

formula for an olivine is written $(Mg, Fe)_2SiO_4$. The silicon-oxygen ratio in olivines is 1:4.

It is possible for SiO_4 tetrahedrons to share oxygen atoms. A single chain in which each SiO_4 tetrahedron shares an oxygen atom with a tetrahedron on either side is the basic unit for another type of silicate mineral with a silicon-oxygen ratio of 1:3. *Pyroxene* is a typical chain silicate. The SiO_3 chains are cross-linked by the elements calcium, iron, and magnesium in various proportions, and the formula is written $(Ca, Fe, Mg)SiO_3$.

In a double-chain silicate, half of the SiO_4 tetrahedrons share two of their oxygens and the other half share one, giving an Si to O ratio of 4 to 11 for the *amphibole* minerals. (See Guide Figure 2–8.) Common linking elements are iron, magnesium, and calcium. Amphiboles, and some pyroxenes, often contain aluminum in place of some silicon.

SiO_4 tetrahedrons can share three oxygens to form a sheet. Only one oxygen of each SiO_4 unit is left unshared. Each silicon atom can be considered to hold this unshared oxygen and one-half of its three shared oxygens, giving a silicon-oxygen ratio of 2:5. Octahedrons containing aluminum or magnesium can also form two-dimensional sheets. The two types of sheet units, tetrahedral and octahedral, are the building units of the *micas*.

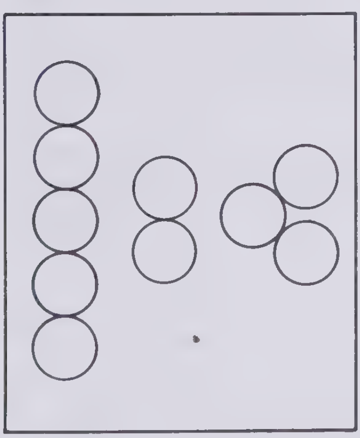
If an SiO_4 tetrahedron shares all of its oxygens, the resulting silicon-oxygen ratio is 1:2. A common example of such three-dimensional sharing is the mineral *quartz*, SiO_2. Related to quartz are the feldspars, the most common minerals in the earth's crust. A *feldspar* results when aluminum substitutes for silicon in the three-dimensional sharing framework. If aluminum substitutes for one-fourth of the silicons, the formula Si_4O_8 becomes $AlSi_3O_8$.

Many kinds of silicate rocks result from various combinations of olivines, pyroxenes, amphiboles, micas, feldspars, and quartz. Some combinations are common and others are rare. The two most common are granitic and basaltic rocks. Names for the different varieties are based largely on their mineral composition and texture.

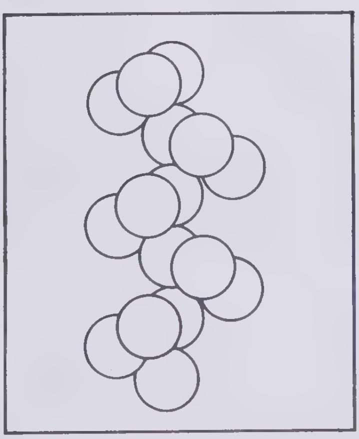
Answers to thought and discussion

1. Why isn't it useful to describe a crystalline solid like sodium chloride in terms of molecules? **Answer** Molecules only describe the type and relative number of atoms found in a substance. They give no clues to the physical properties or to the crystal structure of the substance. A crystalline solid is never found as only one molecule.
2. How are minerals useful in reconstructing past earth conditions? **Answer** Many minerals form only under certain conditions, such as a particular temperature and pressure. If a scientist can determine the conditions under which a mineral forms, he can say that those conditions must have existed when and where the mineral formed.
3. Air, water, and minerals all contain atoms. Why, then, are these materials so different? **Answer** The atoms in a solid, like a mineral, are fairly close together. Each atom is more or less fixed with respect to every other atom. In a liquid such as water the atoms or molecules are close together, but not ordered into a definite pattern. They are free to move

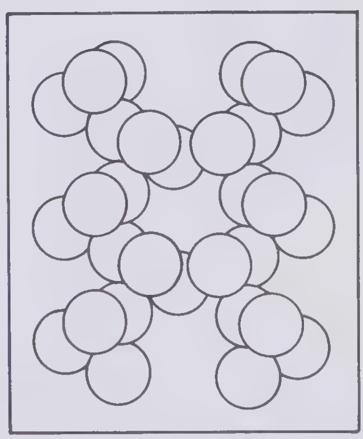
Guide Figure 2–6
String, double, and triple modules.



Guide Figure 2–7
Single-chain silicate (SiO_3).



Guide Figure 2–8
Double-chain silicate (Si_4O_{11}).



about. In a gas such as air the atoms and molecules are moving rapidly and randomly, separated from each other by comparatively great distances.

4. Are the properties of minerals mainly the result of their chemical composition or are other factors more important? **Answer** Mineral properties are mainly the result of *two* factors, composition and the internal arrangement of atoms. For example, two minerals, such as halite ($NaCl$) and pyrite (FeS_2), have the same internal arrangement of atoms but different compositions and properties. But two minerals with the same chemical composition, such as diamond and graphite, derive quite different physical properties from their different internal structures.
5. Can you predict the arrangement of atoms in a mineral specimen by looking at its overall shape? **Answer** Yes. A mineral often reveals its atomic structure by the way it breaks.

2–10 The composition of earth and moon rocks

In Figure 2–25 note particularly how abundant oxygen is in the crust. See if the students can explain the difference between the percentages of oxygen by weight and by volume.

You might emphasize that most minerals will be composed of oxygen, silicon, aluminum, iron, calcium, sodium, potassium, and magnesium.

You can extend the ideas in this section by putting Guide Figure 2–9 on the chalkboard. This information can add another dimension to the students' view of the three earth spheres.

The lithosphere forms almost 100 per cent of the combined mass of the three spheres. More than 99 per cent of the earth's mass lies beneath the crust and thus is totally inaccessible to man. The masses of the hydrosphere and atmosphere are almost negligible. As shown by the table, their combined percentage mass is so small that it does not even appear when the percentage masses of the crust, mantle, and core are rounded off to one decimal place.

Guide Figure 2–9

Earth Sphere	Percentage of Total Mass
Atmosphere	0.00009
Hydrosphere	0.024
Lithosphere: crust	0.4
mantle	68.1
core	31.5

The similarities between the earth and moon, in this sense, are extensive: (1) most of the material is inaccessible to man and (2) there are negligible hydrospheric and atmospheric masses. The materials that make up the moon appear in many ways to be similar to materials of the earth. The type of surface rocks, however, is quite different since sedimentary rocks probably don't exist on the moon's surface.

2–11 The common elements in the atmosphere and hydrosphere

Students may not realize that air is a *mixture* of gases. Make its composition obvious early in the discussion of the atmosphere. You could introduce this subject by asking students about the properties of air. From such exchange, you can establish that air is invisible, colorless, tasteless, odorless, and has weight. The question, "What is it about air that permits burning?" may lead to a consideration of the composition of air. Some students may be under the impression that when a candle burns, air burns too. Develop the idea that it is the oxygen that supports combustion and that combustion occurs when oxygen from the air combines with other elements. A simple example is the burning of carbon, $C + O_2 \rightarrow CO_2$. You might mention also a common example of slow combustion, the process known as rusting: $4\ Fe + 3\ 0_2 \rightarrow 2\ Fe_2O_3$.

Demonstration You can generate oxygen gas by dropping a pinch of manganese dioxide (MnO_2) into 5 milliliters of a 3 per cent solution of antiseptic hydrogen peroxide (H_2O_2). A glowing splint inserted into the mouth of a test tube containing these ingredients will ignite to reveal the presence of oxygen.

Demonstration You can demonstrate that a sample of air contains oxygen as follows: Stuff some steel wool into the bottom of a small glass

jar or beaker. Invert it in a wide, shallow pan about three-fourths filled with water. After a day or so it should be apparent that the water in the inverted jar has risen above the water level in the shallow pan. The steel wool will begin to rust as the iron is oxidized, providing evidence that the missing component in the air, oxygen, no longer exists in a free form.

Oxygen is lost from the air very rapidly if a burning candle is substituted for the steel wool. Place the candle in the center of the shallow vessel, again filled three-fourths with water. Invert a beaker over the candle. The candle soon goes out and water rises inside the beaker.

Students' experiences should provide a background for a brief discussion of water vapor and solids in the atmosphere. You can use such opening questions as: What examples can you cite of water in the atmosphere? Some possible answers: High humidity causes you to feel damp and causes clothing to stick to you. Water droplets collect on mirrors after a shower. Water condenses on pipes in the summertime. Moisture collects on the outside surface of a glass or metal container filled with ice. Fog and dew sometimes form.

Another question might be: What examples can you give of dust or other solid materials in the atmosphere? Pollen floating in the air is a cause of hay fever. Foreign materials like dust or ash in the atmosphere cause brightly colored sunsets, and smog forms from the accumulation of solid as well as gaseous contaminants.

You can use the discussion of the composition of the atmosphere and hydrosphere to compare the composition of the three major spheres. A strange fact will emerge: The atmosphere that supplies man with oxygen actually has a lower proportion of oxygen than either the lithosphere or the hydrosphere. Ask the students what the abundance of oxygen in the three spheres suggests about their origin. The fact that oxygen is a major constituent of all three spheres strongly suggests that they had a common origin.

Answers to thought and discussion

1. The atmosphere and the hydrosphere have remarkably uniform compositions compared to the lithosphere of the earth. Why is this so? **Answer** The atoms or molecules in a gas or liquid are much more mobile than the atoms in a solid. This means that gases and liquids mix more thoroughly. If you stir a teaspoonful of sugar into hot water, it is soon distributed through all the water in the container. If you drop the sugar on a rock, nothing observable happens.
2. If the crust contains such small amounts of elements like copper and lead, how can man obtain these useful materials? **Answer** Although the crust contains only minute amounts of copper and lead, there are places in the crust where these elements are highly concentrated. The minerals containing these elements are mined from such enriched pockets, called ore deposits.
3. Can you suggest reasons why the moon has no atmosphere and hydrosphere? **Answer** The main reason the moon has no atmosphere is its mass. The pull of gravity on the moon is too weak to hold the light gas molecules close to the surface. Because of the high daytime temperature, exposed liquid water would quickly evaporate and then be lost into space. Ice also would evaporate.
4. Look up the composition of the sun. How does the earth differ from the sun in composition? **Answer** The principal elements in the sun are hydrogen and helium. These elements are only minor components of the earth.

Discussion of unsolved problems

Some scientists favor the idea that the earth is made from fragments of space debris. The matter was cold when the earth formed. They say it differentiated into concentric internal layers largely as a result of radioactive heating. The denser material sank, and lighter material rose to the surface. Other scientists believe that the earth initially was composed of hot gases.

The earliest history of the earth is obscured by the many geological processes that have occurred since. The moon is far more homogeneous than the earth. Fewer geological processes have been at work on its surface to obscure its early history. We can learn a great deal about the early history of the earth from studying its partner, the moon. The two bodies seem to have been closely associated almost from their formation.

Answers to questions and problems

A

1. What is the difference between an element and a compound? **Answer** An element contains only one kind of atom or its isotopes; a compound contains two or more kinds of atoms chemically combined.
2. What is an ion? **Answer** An ion is an atom or group of atoms that has become charged through the loss or gain of electrons. Examples are the sodium ion, Na^+, the chloride ion, Cl^-, and the carbonate ion, CO_3^{-2}.
3. What subatomic particles form the nucleus of an atom? **Answer** The primary particles are protons and neutrons.
4. Is ice more or less dense than water? **Answer** Ice (0.9 g/cm^3) is less dense than water (1 g/cm^3). Ice floats on water.
5. How does the abundance of metals in the earth's crust compare with the abundance of oxygen? **Answer** On a weight basis, oxygen comprises 46.6 per cent of the crust, whereas the common metals together comprise only 24.2 per cent. Because of the large size of the oxygen atom, it comprises 93.8 per cent of the crust by volume. By volume and weight, then, oxygen is more abundant than all metals combined.
6. How do earth and moon rocks differ? **Answer** Moon rocks contain very little water in any form compared to earth rocks, but they do contain much higher percentages of titanium, chromium, and zirconium.
7. Why are moon rocks unaffected by chemical weathering? **Answer** The moon lacks an atmosphere and water, which are essential for chemical weathering.

B

1. What is the difference between an atom and an ion? **Answer** In an atom the positive and negative charges balance, but not in an ion.
2. What keeps atoms together in a compound? **Answer** In most compounds atoms are held together mainly by electrical forces.
3. How was the practice of alchemy important to the development of modern science? **Answer** Although the alchemists never succeeded in producing precious metals from other elements, their experimentation helped develop laboratory techniques, and the idea that there exist a number of fundamental substances called elements.
4. Why do minerals appear in the form of crystals? **Answer** Minerals appear as crystals because their atoms or ions are arranged in a fixed internal pattern.
5. What did Lavoisier learn about air? **Answer** He learned that air is composed of several gases, chiefly nitrogen and oxygen.
6. Sketch the arrangement of protons, neutrons, and electrons in helium. **Answer** See Figure 2–13. The nucleus of the helium atom contains two protons and two neutrons and is surrounded by two electrons.
7. If water is composed of two parts hydrogen and only one part oxygen, why does oxygen make up most of the mass of the hydrosphere? **Answer** Because oxygen is almost 16 times as heavy as hydrogen, it accounts for much more of the mass. In the water molecule the mass ratio is about 8:1.
8. What are some of the qualities of gemstones that make them so valuable? **Answer** Almost all gemstones are minerals that form only under special conditions, so they are usually quite rare. In addition, purity of the particular mineral is usually a requirement.

C

1. John Dalton proposed that all substances are composed of small, solid, indestructible particles called atoms. Are atoms still considered to be small, solid, and indestructible? **Answer** Atoms are still considered to be extremely small. However, they are no longer thought to be solid or indestructible. The modern model of the atom views it as having a tiny, dense nucleus surrounded by clouds of electrons. The nucleus contains protons, neutrons, and a number of additional particles. Atoms are destroyed when they are split in nuclear reactors or in atomic bombs. Hydrogen bombs destroy atoms by combining them.
2. How does salt (NaCl) dissolve in water? **Answer** Salt is composed of positive sodium ions and negative chloride ions. The negative ends of the water molecules cluster around the positive sodium ions and gradually work them loose from their place in the salt crystal. The positive ends of the water molecules attach themselves to the negative chloride ions and loosen them from the crystal.

3. What difference in structure accounts for the fact that mica easily comes apart in flakes whereas quartz breaks irregularly? **Answer** Mica has a sheet structure that will break in layers. Quartz has a three-dimensional framework of tetrahedral units that are linked equally in all three directions. This arrangement will not break in a regular fashion.
4. Look at Figure 2–25. Which atom has the larger volume, the Fe atom or the Na atom? **Answer** The Na atom has the larger volume. It makes up more of the crust by volume than Fe, even though Na is less abundant by weight.

Supplementary Materials

Reference books

Dana, Edward S. and Hurlbut, Cornelius S., Jr. *Minerals and How To Study Them*, 3d ed. John Wiley & Sons, Inc., New York, 1972. (Paperback)

Davis, Kenneth S. and Day, John A. *Water: The Mirror of Science*. Doubleday & Company, Inc. (Anchor Books), Garden City, N.Y., 1961. (Paperback)

Davis, Kenneth S., and Leopold, Luna B. *Water*. Time-Life, New York, 1970. Well-written and beautifully illustrated.

Dennen, William H. *Principles of Mineralogy*, rev. ed. The Ronald Press Company, New York, 1960.

Holden, Allen and Singer, Phyllis. *Crystals and Crystal Growing*. Doubleday & Company, Inc. (Anchor Book), Garden City, N.Y., 1961. (Paperback)

Hurlbut, C. S., *Minerals and Man*. Random House, New York, 1968.

Irving, Robert. *Rocks and Minerals and the Stories They Tell*. Alfred A. Knopf, Inc., New York, 1956.

Joseph, Alexander and others. *Teaching High School Science: A Sourcebook for the Physical Sciences*. Harcourt, Brace & World, Inc., New York, 1961.

Strahler, Arthur N. *The Earth Sciences*. Harper & Row, Publishers, New York, 1971. College text treating all the earth sciences. Excellent diagrams and illustrations.

Wohlrabe, Raymond A. *Crystals*. J. B. Lippincott Co., Philadelphia, 1962. (Paperback)

Zim, Herbert S. and Shaffer, Paul R. *Rocks and Minerals*. Golden Press, Inc., New York, 1957. (Paperback)

Films

Crystals. 30 minutes, black and white. Modern Talking Picture Service. PSSC film. Numerous demonstrations, some that students can repeat.

Explaining Matter: Molecules in Motion. 11 minutes, color. Encyclopaedia Britannica Educational Corp. Good explanations of the three states of matter related to molecular movement.

Materials of the Earth's Crust. Ward's Natural Science Establishment, Inc. Set of six color filmstrips totaling 379 frames would be useful with first part of chapter. Separate filmstrip titles: "The Minerals," "Identification of Minerals," "The Rocks," "Igneous Rocks," "Sedimentary Rocks," and "Metamorphic Rocks."

McGraw-Hill Text-Films series. The set includes: "How Rocks Are Formed," "What Are Elements and Compounds?", "What's in the Atom?", "Wealth from Mother Earth," "Atoms and Molecules," "The Atom," "Atomic Structure and Chemistry," "Minerals — How They Are Identified," "Crystals," and the filmstrip, "Structure of the Atom."

Rocks for Beginners. 16 minutes, color. Johnson Hunt Productions. Good, simple description of origins and characteristics of the major groups of rocks.

Rocks That Originate Underground. 23 minutes, color. Encyclopaedia Britannica Educational Corp. Reconstructs geologic conditions inside crust by use of indirect evidence. Investigates crystalline mineral grains and crystal growing.

The Structure of Atoms. 12½ minutes, color. McGraw-Hill Text-Films. Provides experimental evidence for our basic concepts of the structure of the atom.

The Structure of Water. 14 minutes, color. McGraw-Hill Text-Films. Describes molecular polarity, dipole attraction, and hydrogen bonding between water molecules.

What Are Things Made Of? 11 minutes, color. Coronet Films. Describes composition of matter and its three states, atoms and molecules, elements and compounds, as well as chemical and physical changes.

3. The Changing Earth

Chapter Objectives

After completing this chapter, students should be able to:

1. Give examples of the three ways heat can be transferred from one place to another.
2. Account for the principal sources of earth's heat energy.
3. Explain how the decay of radioactive elements generates heat energy in the earth's crust.
4. Describe how heat is generated in the sun and transferred to the earth.
5. Use Newton's laws of motion to account for common experiences involving inertia, momentum, velocity, speed, and acceleration.
6. Solve problems using the formulas $F = Ma$ and $F = \frac{GM_1M_2}{d^2}$.
7. Describe the earth's magnetic field, including field intensity, inclination, and declination.
8. Explain how measurements of gravity and of magnetism can aid in the discovery of mineral resources.

Teaching the Chapter

This chapter is full of important concepts basic to many branches of science. Experience has shown that there is a point of diminishing returns in developing these concepts at this point in the course: *too much time and too much depth kill interest.*

Early in the chapter long-term investigations are introduced that will require continuing attention over several weeks or longer. Three other investigations are completed during the study of the chapter. This means that in most cases you can tie discussion of the topics directly to an activity. If students need additional experience working with the topics of energy, fields, and forces, the investigations can be expanded.

Let class discussions on the chapter topics concentrate on commonplace experiences with energy forms and transfer, forces and motion, and gravity and magnetism. Discussions of gravity and magnetism tie in with the concept of a field. From here on in the course, you can encourage the students to recognize and refer to fields in other contexts, as well.

Suggested time required

It should take eight to eleven periods to discuss the topics and complete the investigations in this chapter.

Section Notes

3–1
Motions of earth materials

Student observations of change in the environment probably will include changes other than those involving the atmosphere, oceans, or land areas. Let class discussion try to decide which reported changes involve energy.

It is too early in the course to consider the questions included in this section in any detail. An interesting exercise is to let the students guess at answers if they want to. They may balk because they fear giving wrong answers. You can remind them that one aim of science is to develop the ability to guess.

3–2
Investigating patterns of change — Weather Watch

Advance preparation

Instructions for making simple rain gauges are found on pages 46 and 47 of *A Sourcebook for the Physical Sciences*, listed in Supplementary Materials for Chapter 2.

Decide where observations will be made and how the equipment is to be used. If possible put

the instruments in a small shelter 1.5 meters above the ground on a fence or post. This position has the most desirable exposure and conforms to international meteorological standards. Specifications for an instrument shelter are included in the U.S. Weather Bureau's Weather Science Study Kit. (See Materials.)

Look ahead to Investigation 7–1 to see how the Weather Watch data will be used.

Time requirements

Pre-lab	30–40 minutes
Lab	5 minutes a day
Post-lab	delay until Chapter 7

Materials

The following materials should be available to each class:

- Rain gauge or can
- Graduated cylinder, 50 ml, if can is used for rain gauge
- Anemometer, wind meter, or wind gauge
- Barometer
- Thermometer (use a recording barometer and recording thermometer if possible.)
- White shelf paper or data sheets
- Maximum-minimum thermometer (optional)
- Psychrometer (optional)
- Cloud Code Chart, Instructions for Climatological Observers, Circular B, and Weekly Weather Map, ordered earlier from the U.S. Government Printing Office
- Weather Science Study Kit (U.S. Weather Bureau), U.S. Government Printing Office, Washington, D.C., $1.00 (optional)

Pre-lab discussion

When you introduce the investigation, call attention to the fact that weather changes appear to be random events. The class is going to keep track of weather elements — wind, sky conditions, air temperature, moisture, precipitation, air pressure, and cloud formations — to see what patterns can be detected over long periods of time. Students should expect to identify patterns that can be used to make predictions about the weather. In Chapter 7 students will summarize the data from the wall chart to see what patterns and relationships appeared.

There are many different ways to introduce the instruments, but it is important to show the students each instrument as you explain its use. Most of the instruments are fragile, so show students how to handle them carefully. Spend a few minutes demonstrating how each instrument measures a weather variable.

You may want to take the class outside and have some of the students practice with each instrument. If you do this, have students measure air temperature at different places: near the ground, in a shadow, in the sun, and above a sidewalk. Then have the class decide where air temperature should be read each day.

Assign several students to make the class Weather Watch chart from a continuous roll of paper or data sheets taped together.

Notes on procedure

It is not necessary for students to keep individual records of the daily data. A single chart can act as a resumé used by all.

Show how to use the Weather Watch chart (Figure 3–1) by entering one set of values in the proper columns. If your classroom's wall space is limited, you can roll the chart at the ends like a scroll. Try to mount the chart so that a few weeks can be seen at once. The data recording might be done during the first few minutes of each class. Assign individual students the responsibility of bringing newspaper weather reports to class to fill in weekend and holiday information.

Point out that the Weather Watch chart uses the 24-hour clock notation for consistency with international and space-data communications practices.

If a recording thermometer (thermograph) is used, transfer the curve to the wall chart for comparison with other data. If a recording barometer (barograph) is used, transfer that curve to the wall chart as well. If there is no barometer available, the student responsible for the day's pressure measurement can get the barometer reading from the local news or weather reports on radio or television. It is necessary to convert millimeter readings to millibars if your barometer does not record directly in millibars. (1 millimeter of mercury = 1.33 millibars) Normal pressure at sea level is 1013.25 millibars.

Remind students that wind direction is the direction *from* which the air moves. Students record wind direction on the chart by drawing a line representing the compass direction from which the wind is blowing. North is considered

to be the top of the chart. The wind speed value is drawn on the end of the wind direction line.

The recommended procedure for describing sky condition is to estimate the percentage of the sky covered by clouds and then to record the sky conditions as clear, partly cloudy, or cloudy. Guide Figure 3–1 shows one set of symbols commonly used to designate sky conditions.

The class may choose to denote cloud types as either "layer" or "puffy" or to use the classifications of the U.S. Weather Bureau Cloud Code Chart. You may devise your own symbols for denoting cloud type or use the weather plotting code of the Daily Weather Map.

Enter the state of the weather at the time of observation as rain, snow, thunderstorms, clear, cloudy, fog, haze, smog, or any other description that applies. Encourage single-word descriptions.

The rain gauge should be away from buildings and trees and about 1.5 meters above the ground. If the funnel of the gauge has a diameter larger than that of the collecting container, you will have to make corrections to find the amount of actual precipitation. It is most convenient to have the area of the funnel opening be ten times as great as the area of the bottom of the container. Then one millimeter of precipitation in the container represents 0.1 millimeter of actual precipitation. Have two collectors available so that one can be in place if the other must be taken from its exposure site during precipitation.

Measure snow on a level place with a meter stick. Compare the snow cover measurements obtained by different classes during the day and let the students speculate on why they vary, if they do. Snow caught in the precipitation collector should be melted to obtain its water equivalent.

Some discussion usually arises about the effect of weather on people. Students may wish to keep track of the number of people absent from school, the number of death notices in the local paper, or the number of automobile accidents or thefts reported to the local police department each day. At the end of the investigation, the class can see if any of these events appear to have any relationship to the weather data. (See Investigation 7–1.)

Guide Figure 3–1
Symbols to show sky condition on the Weather Watch chart.

Sky Condition	Cloud Cover	Symbol
Cloudy	*More than eight-tenths of sky covered.*	●
Partly cloudy	*Two-tenths to eight-tenths of sky covered.*	◑
Clear	*Less than two-tenths of sky covered.*	○

Range of results

Figure 3–1 shows a typical Weather Watch chart.

Post-lab discussion

The Weather Watch data will be summarized as part of Investigation 7–1.

3–3
Investigating patterns of change — Earthquake Watch

Advance preparation

As soon as possible, order the "Preliminary Determination of Epicenters" sheets, published weekly by the Environmental Science Services Administration of the U.S. Department of Commerce. Send your request to Coast and Geodetic Survey, Rockville, Maryland 20852. There may be a small service charge.

If for some reason you do not receive your Epicenter data sheets, students can plot earthquake focuses from the information in Appendix D instead. As a last resort this backup material will let your students complete the investigation, but it is much better for the class to receive the current Epicenter data sheets.

Time requirements

Pre-lab	15 minutes
Lab	5 minutes a day
Post-lab	delay until Chapter 11

Materials

The following materials should be available for each class:

- Pacific-centered Mercator world map, 75 cm × 100 cm, from Earthquake Watch Kit.
- Map pins, 100 each of 3 colors
- Epicenter data (see Advance Preparation)

Special notes

To show the earthquake pattern clearly the world map should have the Pacific Ocean intact, not

split into two parts. It also must have lines of latitude and longitude plainly marked.

Pre-lab discussion

Ask the students how many have felt earthquakes. If more than one student has, ask how they might decide if they felt the same quake.

Point out that seismologists have ways of locating with some precision the focus of an earthquake. In this study your class will keep a record of earthquake activity by plotting such data on the map.

Review map plotting procedures. Students must be able to use latitude and longitude correctly. The most common mistake is confusing east and west longitude.

Notes on procedure

The Epicenter sheets will list the following data:

- Date of earthquake
- Greenwich Mean Time (the time at zero degrees longitude, the Prime Meridian, which passes through Greenwich, England)
- Latitude (number of degrees north and south of the equator)
- Longitude (number of degrees east or west of the Prime Meridian)
- Region (geographic location of epicenter)
- Depth (depth of focus in kilometers)
- Magnitude (severity of earthquake on the Richter Scale, given in Figure 13–9)

The Epicenter sheets will list so many very small earthquakes that only earthquakes of magnitude greater than 4.0 need to be plotted. You might want to duplicate the Richter Scale in Figure 13–9 and post it near the map.

One way to avoid recording earthquakes more than once is to check off on the cards the earthquake location data as it is plotted on the map.

A legend should appear on or near the map where the earthquakes are recorded. You may use either india ink symbols or pins of different colors (see Guide Figure 3–2).

Guide Figure 3–2
Symbols to show earthquake depth.

Type of Earthquake	Depth	Symbol with Suggested Colors	
Shallow	*0-69 km*	*	*(asterisk) red pin*
Intermediate	*70-299 km*	△	*(clear triangle) yellow pin*
Deep	*300 km or greater*	▲	*(darkened triangle) blue pin*

Range of results

A typical map appears at the completion of this investigation in Section 11–5.

Post-lab discussion

The Earthquake Watch will be summarized in Chapter 11.

3–4 Energy

You can give some examples defining energy as the capacity to do work. Ask questions such as: Is the same amount of work involved in sliding a book for a distance of one meter along a table top as in raising the book one meter to put it on the shelf? No. What forces are you working against in each instance? Friction in the first case and gravity in the second. Friction must be overcome in sliding the book, and gravity must be overcome in raising it. Different amounts of work are required to overcome them. If you push until you're tired against a boulder that does not move, how can you say that no work is being done? Force $\times$ Distance = Work; Force $\times$ 0 = 0. You can expend energy, yet do no work. What happened to your energy? It was used up in the form of chemical energy by the muscle and metabolic systems of your body and then expended mostly as body heat.

After students have studied the flow of energy represented in Figure 3–4, ask them to give other examples, such as the flow of energy in pedaling a bicycle to the top of a hill and coasting back down to the bottom. The chemical energy from food is changed to mechanical energy as muscle movement powers the bicycle to a higher elevation. Energy is lost to friction in going up- and downhill. Another example would be to show how energy flow applies in a steam engine. Chemical energy is changed first to thermal energy and then to mechanical energy.

When the class discusses Figures 3–5, 3–6, and 3–7, point out that only radiation can take place through a vacuum. Students may find radiation more difficult to understand than conduction or convection. You can demonstrate radiation by placing a piece of copper on a sunlit windowsill with the window closed. After a while, ask students to touch the copper and to report on the temperature of the copper. It will be warmed by the sun's radiation.

Students might be asked to explain why grocery stores can have refrigerator counters that do not have tops. Since cold air sinks, the lack of a top does not prevent the items in the counters from remaining cold. While a top makes the unit more efficient, efficiency is sacrificed for convenience. Ask why cold air spills onto your feet when you open a refrigerator door.

3–5
Investigating flow and change in energy

Part A

Time requirements

Pre-lab	5 minutes
Lab	25 minutes
Post-lab	10 minutes

Materials

The following materials will be needed for each group of three or four students:

- Radiation Kit, or:
  - Shiny metal can, 6 oz
  - Black metal can, 6 oz
  - Insulating lids with slits, 2
  - Thermometers, range −20°C to 50°C, 2
  - Lamp, 200 watts, without reflector
- Graph paper

Special notes

An adequate number of electrical outlets must be available for this investigation, even if you have to set up temporary wiring. *All electrical connections must be safe.*

Pre-lab discussion

Review the role of a physical model in an investigation. Then ask how this investigation might be a model of the sun-earth relationship.

Notes on procedure

The thermometers should start at the same temperature, and the bulbs should be at the same level in each can. Thermometers should not touch the bottoms of the cans. Each can should be the same distance from the center of the light bulb. Neither the light bulb nor the cans should be moved during the investigation.

Let students plan their own procedure as far as possible. They may find, for example, that a different time span gives better results for their setup.

Students should plot the heating and cooling curves for both cans on the same sheet of graph paper, using different symbols to designate the black can and the shiny can.

Range of results

The amount of rise in temperature will vary with the distance from the light. In all cases the black can should heat more than the shiny can. A sample student graph is shown in Guide Figure 3–3.

Post-lab discussion

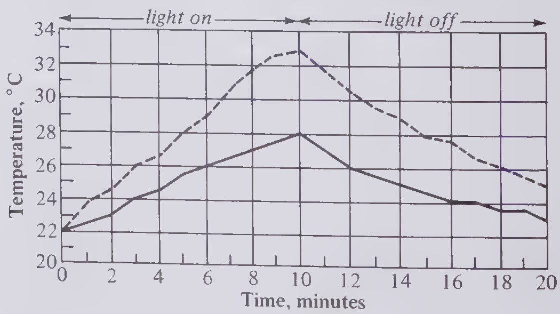
Compare the student graphs. If any are obviously not in agreement have the students attempt to supply the reason. This provides an opportunity for students to discuss possible sources of error in the investigation.

While this investigation is still fresh in their minds, start the students thinking about the paths of energy and the materials through which energy passes. One way to do this is to ask students for examples of how different materials react to the sun's energy with different temperature changes.

Answer to questions

1. Which can heats faster? **Answer** The black can.
2. Which can cools faster? **Answer** The black can.
3. Which can absorbs energy better? What is your evidence? **Answer** The black can, because the temperature inside it increased more rapidly and reached a higher temperature than the shiny can in the same amount of time. The slope of the graph for the black can is steeper.
4. Which can loses energy faster? How do you know? **Answer** The black can, because the temperature inside it decreased more rapidly

Guide Figure 3–3
Sample heating and cooling curves for Part A of Investigation 3–5. The dotted line indicates the black can.



than that in the shiny can. The slope of the cooling line for the black can is steeper than the one for the shiny can.

5. How was the energy transferred in this investigation? **Answer** Energy transfer took place from the source of electricity along a wire to the bulb filament and was radiated from the filament through the vacuum in the bulb. Energy was conducted and radiated through the glass and then radiated through the air to the side of the can. It then was conducted through the metal can, radiated through the air to the thermometer bulb, and finally conducted through the glass to the liquid in the thermometer, which expanded when it was heated.
6. List and describe the forms of energy you observed. **Answer** Heat or thermal energy, light, and electrical energy.

Part B

Advance preparation

Have a source of boiling water on hand, or provide equipment for boiling it in class.

Time requirements

Pre-lab	5 minutes
Lab	25–30 minutes, if boiling water is supplied.
Post-lab	10 minutes

Materials

The following materials will be needed by each group of two students:

- Heat Transfer Kit, or:
  - Insulated containers, 2
  - Insulating lids with slits, 2
  - U-shaped aluminum transfer bar
  - Thermometers, range −10°C to 100°C, 2
- Boiling water, 150 ml
- Water at room temperature, 150 ml
- Graph paper

Special notes

Warn students to be careful handling boiling water. Saftey glasses should be worn by students working with open flames and boiling liquids.

Pre-lab discussion

Briefly explain that the plastic containers are calorimeters, a type of equipment that is designed to minimize heat loss or gain.

Notes on procedure

Slots in the styrofoam lids of the calorimeters will wear and permit heat energy to escape if the aluminum bar or the thermometers are worked back and forth.

Students will get better results if during the investigation they do not place the calorimeters near places that are unusually hot or cold. Preheating the hot water calorimeter, by swirling some hot water in it before adding the water to be used in the investigation, will eliminate some heat loss.

Since the instructions don't say how much water to add, you might have one group of students add different amounts to each calorimeter. The other groups should add the same quantity to each container.

Reading the thermometers every *two minutes* will yield better results. When the data is collected, the students construct a graph showing both hot- and cool-water curves.

Range of results

The hot-water curve should slope down to the right, and the cool-water curve should slope up to the right. The two curves should approach, possibly meet, but not cross.

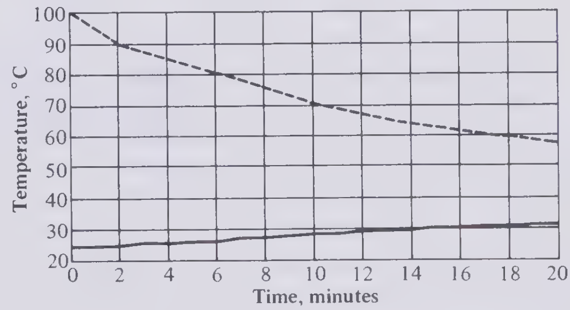
The slopes of the curves graphed by the students will vary, depending on their calorimeters. A sample graph is shown in Guide Figure 3–4.

Post-lab discussion

Even though the students may not have much of a technical vocabulary they should be able to describe the sequence of events and the energy flow that took place in the investigation when they discuss the questions. Use the students' own answers to help them see that if you know the temperature distribution of a system, you can predict the direction of energy flow.

Guide Figure 3–4

Sample heat transfer graph for Part B of Investigation 3–5. The dotted line indicates the black can.



At this point it might be worth pointing out that the temperature change in this investigation is a measure reflecting energy flow. This is because identical calorimeters are used and the same amount of water is placed in each. Ask if the results of the group that used different amounts of water are as good a measure? Why not?

Answers to questions

1. In which direction does the energy flow? What is your evidence? **Answer** The energy flows from the hot-water calorimeter toward the cool-water calorimeter. The evidence can be seen in the graph. It indicates that the temperature (energy level) decreased in the hot-water calorimeter and increased in the cool-water calorimeter. Also, the transfer bar became warmer due to the flow of energy through it from the hot-water calorimeter.
2. Does energy loss equal energy gain? Explain why. **Answer** Energy loss *does not* equal energy gain. The increase in temperature of the cool-water calorimeter is not as great as the temperature decrease in the hot-water calorimeter. Some energy is lost by radiation from the metal bar, as well as through the hot-water calorimeter itself.
3. Describe the kinds of energy flow you observed in this investigation. **Answer** The connection between the two calorimeters is the metal bar, so most of the heat energy must have moved along or through the bar. Some heat energy must have escaped from the bar into the air, and some must have moved from the water to the sides of the calorimeters. There was also conduction and convection within the water.
4. What could you do to make the final temperature readings in Part B higher? **Answer** Some possibilities are: (1) add insulation to the metal bar to decrease the escape of heat energy to the air, (2) shorten the length of the bar to decrease energy loss during its movement along the bar, (3) increase the cross section-to-length ratio of the bar, and (4) preheat the calorimeter containing hot water.

Suggested additional investigations

Ask students to predict the outcome of Part B of the investigation over five hours instead of 20 minutes. Ask them to graph their predicted results. Then let them test their predictions. They can read the thermometers less often.

Students may want to try variations of this investigation. They might fill the cans used in Part A with various earth materials (water, sand, damp or dry soil) and study the effects. They could also investigate the effect of filters of different colors put between the light source and the cans.

To varv Part B, students might use transfer bars of different metals or different liquids in the calorimeter. Some students may wish to do the investigation again, using the suggestions for improving the equipment given as part of the answer to question 4, Part B.

3–6
The earth's sources of energy

If the students calculate the temperature at the center of the earth based on a 1°C increase for every 30 meters of depth, they will get a fantastically high temperature, over 200,000°C. By comparing this with the recent estimates of 4000°C they can conclude that the rate of increase is not constant.

An example of a faulty extrapolation more familiar to most of us is the weight of an adult predicted from his weight gain the first year. A seven-pound baby who weighs 20 pounds on his first birthday is unlikely to weigh 325 pounds when he's 25.

To find additional material on the subject of average increase of temperature with depth beneath the earth's crust, look under *geothermal gradient* in geology textbooks and other references.

Action Radioactive decay is a discussion topic that interests most students. The Cloud Chamber Kit will help students appreciate one aspect of radioactivity and can lead to a consideration of how the earth replenishes its interior thermal energy.

Demonstration Project the sun's image through a telescope onto a sheet of paper. Students can trace the movement of any sunspots they see over a period of weeks. This can form the basis for a discussion of sunspot cycles.

Impress upon students the importance of not staring directly at the sun, even through filters.

They can seriously damage their eyes. The fact that students have all glanced at the sun many times without suffering eye damage may make this point difficult to get across.

Part One of the film *Our Mr. Sun* is useful in a discussion of the sun. (See Supplementary Materials.)

Another discussion of the significance of large numbers and powers of ten might be helpful here. Some of the large numbers in the text can be written on the blackboard in conventional form to demonstrate the conveniences of using powers of ten.

Answers to thought and discussion

1. On a hot day we can observe a "shimmering" effect that extends upward above pavement or soil. These are popularly called "heat waves." What produces the shimmering effect? **Answer** When the air is calm, heating the pavement or bare ground produces very hot air near the heated surface. This unstable air expands and rises through the cooler air above it. The hot air is rising and cool air descending in small colunms. The difference in density of these air columns produces complex refraction (bending) of light rays passing through them. Variations in the light reaching our eyes creates the shimmering effect.
2. What happens to the enormous amount of the sun's radiant energy that does not strike the earth? **Answer** Some of this energy strikes the moon, other planets and moons in the solar system but nearly all of the total travels out into distant space.
3. What are the various sources of energy received by the earth's surface? **Answer** From most to least heat received the sources are: the sun, the earth's interior, and all the other stars.

3–7
Forces and motion

This section contains many ideas that will probably be new to the students. It is essential not to try to teach all about motion. Simply help the students grasp the main ideas. Examine the section carefully and decide what level of development is appropriate for your class.

Many questions about forces and motion don't involve math. You could ask, for example: Must a force always push right on something to move it (like your pushing a car)? Students will probably name gravity and magnetism as forces that act on objects without physical contact.

3–8
Gravity

How often you use the formula for the law of gravitation will depend on the level of the class. Not all classes will be able to handle the mathematics without your help. Since the calculations may look frightening because they contain powers of ten, you can simplify the work by using numbers that are easy to manipulate.

If F remains constant, the numerator increases when the denominator decreases, and vice versa. If d remains constant, F increases with an increase in either M_1, M_2, or both. If the students understand the relationship between force and distance, they should be able to explain why the attraction between the earth and a distant star is so much smaller than that between the earth and the sun.

When the graviation formula is solved for G, the value is always the same. The constant G is one of the fundamental numbers of science. You might have a student report to the class on how the value of G was determined. Any standard encyclopedia should contain an account of the Cavendish Experiment.

3–9
Investigating the behavior of a falling object

Advance preparation

Check to see that tape moves freely through the timers. Check the battery source and the wiring on the buzzer. Select appropriate locations for the timers. Weights in Part B should fall a distance of at least one meter.

Time requirements

Pre-lab	10 minutes
Lab	20–30 minutes
Post-lab	10–15 minutes

Materials

The following materials will be needed by each group of two or three students:

Acceleration Kit or:
- Time interval marker
- Interval marker tape, 1 roll
- Carbon disks

Dry cell, 1.5 volts
Metric ruler
Scissors
C-clamp
Glue or rubber cement
Construction paper, dark-colored
Weight

Pre-lab discussion

Acquaint students with some problems they can expect from the equipment, such as flapping tape, friction as the hammer strikes the tape, friction of tape in the timer guide, lack of straight falls, and errors in measurement. Go over solutions to these situations that may not be readily apparent to the students.

Make it clear that the information students obtain in Part A will be used in Part B. *Be careful not to take away the element of discovery in this investigation by telling the students what results to expect.*

Notes on procedure

Let students proceed on their own using the directions in the text. As usual, circulate around the room observing and questioning students and noting how they operate the equipment.

Have students complete the graphs for Part A before they go on to Part B.

Range of results

The motion graphs will vary greatly because of the different ways students use the equipment. Some will try to pull the tape as fast as they can; others will be less forceful. See Guide Figures 3–5 and 3–6 for examples of how the graphs might look. Student results rarely will be as even as Guide Figure 3–6, but the overall shape should be the same.

Post-lab discussion

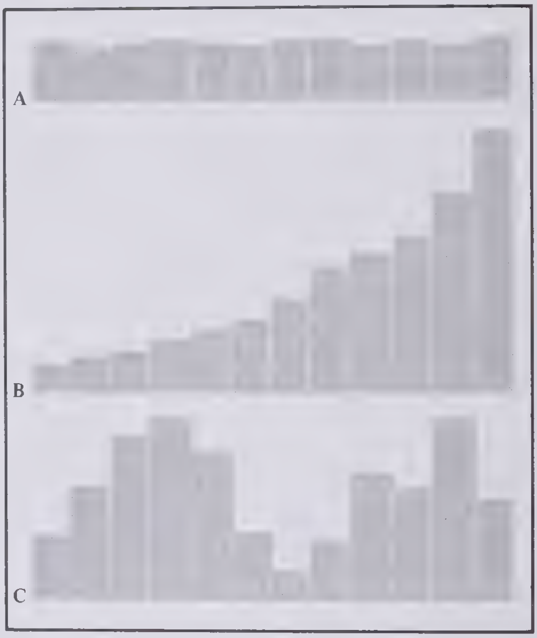
Each group finds that its graph for Part B looks like the others regardless of the mass that is accelerating. For most classes this will provide sufficient post-lab discussion.

You might ask students to suggest an actual situation analogous to each graph. For example, which graph represents a car starting from a stop light? Graph B in Part A or the graph in Part B does. Which graph represents a car traveling at the speed limit? Graph A in Part A does. Which graph represents a student hurrying to class but meeting friends as he moves along? Graph C in Part A does.

Answers to questions

1. What force pulled the tape through the timer in Part A? In Part B? **Answer** In Part A the force was human effort; in Part B the force was gravity.
2. Which of your graphs in Part A closely resembles your graph in Part B? **Answer** The

Guide Figure 3–5
Sample tape strip graphs for Part A of Investigation 3–9.



Guide Figure 3–6
Tape strip graph of a falling object for Part B of Investigation 3–9.

Part B graph should be most like the graph in Part A showing an accelerating rate.

3. How does your Part B graph compare with the Part B graphs of other groups? **Answer** The answers will vary since equipment and procedural differences probably will produce some discrepancies. The overall shape, however, should be similar.
4. Does the behavior of the falling object in Part B change in different parts of the room? **Answer** The object should show nearly identical acceleration in all parts of the room. Careful investigating should show that any variations are caused by differences in equipment and procedure.
5. If the time that elapsed between the dots on the tape is one hundredth of a second, what is the speed of the tape in centimeters per second in your steady-rate graph? **Answer** This will vary from group to group because the students pull at different steady rates. It should be noted that since the spacing between dots remains the same for each 1/100-second interval, any typical bar length can be measured and the speed calculated. Speed equals distance divided by time.

SUGGESTED ADDITIONAL INVESTIGATIONS

A student may use a calibrated timer and calculate the acceleration due to gravity. The timer can be calibrated very accurately with a stroboscope, or approximately with a metronome. To use a metronome, students must adjust the falling distance of the paper and weight so that the time of fall coincides with the metronome beat. Count timer intervals during the time of fall to find the frequency of the timer.

If you want to quantify some of the data, the time between marks will have to be calculated for each individual timer. This may be done by counting the number of dots during a ten-second period. To do this the students will have to pull the tapes through the timers for ten seconds. Having calibrated their timers, the students can measure the distance traveled during one time interval (five dots or more). Divide that distance by that time interval. If the adjacent interval has a different average speed, the acceleration is represented by the difference between the two averages. The students should find that the change in speed shown by all the graphs for Part B is nearly the same. There will be minor differences because of timer variations and tape problems.

The value of the acceleration due to gravity can be calculated from this data if you know the exact time between clicks of the timer. Experience has shown, however, that with this apparatus the results rarely are accurate enough to check very closely with the accepted value of 9.8 m/sec^2.

3–10
Measuring the earth's gravity

The force of gravity at the earth's surface has been defined as 9.8 newtons. In Investigation 3–9 the students determined the acceleration of a falling object due to the force of gravity. Ideally the result should have been 9.8 m/sec^2. Students can suggest many reasons to explain why their results did not exactly agree with this figure. For example, the fall of the light object was retarded by friction, and the timing mechanism was not precise. In spite of all this, the results were not extremely far from the ideal. They should approximate the right order of magnitude.

Gravity may be measured with great precision, but not by the method the students used. Precise methods of measurement are of two types: those designed to measure absolute gravity, and those designed to measure relative gravity.

Absolute gravity is most precisely measured with specially-designed pendulums. The time it takes a frictionless pendulum to swing back and forth is, of course, related to the acceleration of the pendulum's mass. The unit of acceleration is the gal (for Galileo). Gal is defined as the acceleration imparted to a mass of one gram by a force of one dyne acting for one second. This is an acceleration of 1 m/sec^2. Variations in gravity (either absolute or relative) over distances measured in kilometers or tens of kilometers are so small that they are usually expressed in milligals (10^{-3} gal).

The most precise determinations of gravity by pendulums give the following results.

Equator — 978.049 gal
Poles — 983.221 gal

This shows a difference of 5.172 gals, or about 0.5 per cent. Can your students think of a cause for the difference? The difference between the polar and equatorial radii of the earth causes the difference.

This difference can be converted to something more familiar to students by relating gravity to weight. Most of your students live closer to 45°N latitude than to either the pole or equator. As-

sume that gravity in your locality is 980 gal. Have students calculate what their weight would be at the equator. For example, a student who weighs 100 pounds in the classroom would weigh 99.75 pounds at the equator.

Relative gravity is normally measured by instruments known as *gravimeters*. Most gravimeters are in principle very sensitive spring scales. In effect, gravimeters weigh the pull of gravity on any small mass.

A gravimeter survey may start at any convenient point. This point becomes the base value for the survey. All later determinations are compared to this value. Other points in the survey are chosen to form a grid pattern. Depending on the objectives of the survey, they may be tens or hundreds of meters apart. The difference in gravity between each grid point and the base station is plotted on a map and contoured much the way altitude would be. The differences are very small, usually a few hundredths of a milligal, rarely as much as one milligal. The values shown for the gravity variations over a salt dome in Figure 3–16 may be assumed to be in units of 0.1 milligal.

All gravity measurements must be corrected for latitude and altitude. Local topography also can affect the measurements. Intensity of the gravity field may decrease toward a high mountain because of the upward pull of the rocks above the instruments. Relative gravity may increase or decrease because rock layers are close to the surface in some areas or farther from it in others.

3–11
Magnetism and the earth's magnetic field

The discussion of the earth's magnetic field, in contrast to the discussion of gravity, places more emphasis on direction than on magnitude. One reason is that the direction of the magnetic field at a point is easily determined with simple instruments. Instruments for measuring the intensity are based on more complex physical principles.

If possible, students should experiment with simple bar magnets. When they are familiar with the idea that unlike poles attract and like poles repel, you can ask: Is the north-seeking pole really the north pole of a magnet or a compass needle? By custom and tradition the answer is yes. However, it should be the *south* pole of the magnet that "seeks" or points toward the magnetic pole located in the arctic. Compasses continue to be reliable in spite of this confusion.

Demonstration Try to bring to class a compass that has a small coil of wire around the south end of the needle. If you can show students such a compass, ask why the wire is there. It is a weight put on more precise compasses to keep the needle from tipping downward at the north end. This tipping is normal since the lines of magnetic force dive into the ground except along the magnetic equator. See Figure 3–17. Near the equator the needle balances when the wire is near the needle's pivot, but in the arctic regions the coil must be moved toward the south end of the needle to balance it. Where would the coil of wire be on a compass needle used in the Southern Hemisphere? It would be on the north end of the needle as the magnetic intensity there is inclined toward the south.

3–12
Investigating magnetic fields

Advance preparation

Find out the magnetic declination for your area.

Time requirements

Pre-lab	5 minutes
Lab	15–20 minutes
Post-lab	10–15 minutes

Materials

The following materials will be needed by each group of two students:

- Plastic sphere with a bar magnet inserted from Magnetic Sphere Kit
- Round, flat, covered plastic container from Magnetic Sphere Kit
- Magnetic compass
- Iron filings

Special notes

With use the iron filings become magnetized and must be replaced.

Various nearby magnetic objects such as metal poles, automobiles, and belt buckles may produce incorrect readings for the magnetic declination.

Pre-lab discussion

Let the students recount their experiences with magnets and magnetism. You can ask such questions as: Is magnetism three-dimensional?

Notes on procedure

Have the students shake enough iron filings into the container to lightly cover the bottom and then put on the cover.

As the students move the plastic container around the sphere with the magnet inside, the iron filings will line up in the direction of the field. By watching the filings and noting the region of greatest response, students can locate and mark the magnetic poles. To discover the shape of the field, students must continue rotating the sphere or moving the plastic container around and watching the iron filings.

For the second part of the investigation, students measure magnetic declination by finding the angle beween the compass reading and a north-south line constructed in Investigation 1–7.

Range of results

All students should be able to locate the magnetic poles of the sphere. Most students will be able to draw a picture of the magnetic field in answer to question 2. (See Guide Figure 3–7.) All students should be able to measure the magnetic declination in answer to question 4, but they may not be familiar with the term. If the value found for declination is markedly different from what it should be, it is possible that the compass reading was taken near metallic objects such as pipes or wires carrying electric current. This would introduce an error.

Guide Figure 3–7
The magnetic field of a bar magnet curves from one pole to the other.

Post-lab discussion

Some discussion of sources of error in determining magnetic declination will be necessary if the students' answers vary a great deal.

You might ask students questions based on Figure 3–18, for example: What is the declination at a point between the north magnetic pole and the geographic north pole? It is 180°. The north end of the needle will point directly *away* from the geographic north pole.

Students may question you about the nature of a field. The text states that a field is the region where a force can be measured. Since the results of this investigation do not provide numerical values, how can they be used to represent a field? Although the equipment used in this investigation does not supply values that are expressed by numbers, the iron filings do give an indication of relative strength of the field at different points. For example, vary the distance between the container and the plastic sphere and notice the effect on the filings. A numerical value for magnetic field strength requires a gravimeter.

Answers to questions

1. What evidence do you have that the field is three-dimensional? **Answer** The students should see that the iron filings position themselves in all directions around the sphere. At each position some of the particles will point in the direction of the magnetic field.
2. Draw a picture of what the magnetic field would look like if you could see it. **Answer** The general shape of the magnetic field is shown in Guide Figure 3–7.
3. How could you distort the field? **Answer** By placing another magnetic or iron object in it. You might have the students put the like poles of two magnets together and sketch how the fields would be distorted.
4. How does the compass indication compare to the north-south line? Explain your observation. **Answer** The difference between the two should be equal to the magnetic declination for your area.

3–13 Changes in the magnetic field

The slow drift of the field changes the magnetic declination of an area over a period of years. One

way to show that this change has a practical importance is to display some revisions of the *isogonic* maps used for accurate surveying with a compass. How much does the declination change?

When the class discusses Figure 3–20, you might ask students to suggest possible reasons for the wandering of the magnetic pole. No one can explain the changes fully, but many scientists take the data as evidence that major land areas have not always been in the same positions they are now. You might refer back to Figure 3–20 when you reach the discussion of continental drift in Chapter 11.

Answers to thought and discussion

1. How does the mass of an object affect the gravitational attraction it produces? **Answer** The gravitational attraction of an object is directly proportional to its mass. However, it is not clear why matter has gravitational attraction.
2. How does the distance between objects affect the gravitational attraction between them? **Answer** The attraction is inversely proportional to the square of the distance. Students will readily accept the idea that the attraction should decrease with distance. Their first guess, even after they have studied the formula, may be that the decrease should be directly proportional to the distance, instead of the square of the distance.
3. How does the shape of the earth make the attraction of gravity at the poles greater than at the equator? **Answer** Due to rotation the earth is not a perfect sphere. It is flattened at the poles and bulged at the equator. The polar radius is a little shorter than the equatorial radius. At the poles an object is closer to the center of the earth so the pull of gravity is greater.
4. What is gravity field intensity, and how is it useful? **Answer** The field intensity is a measure of the pulling power of gravity. From studying how gravity in a region varies, scientists can locate underground rock formations and mineral resources.
5. Would you expect a buried deposit of lead ore to cause gravity to be relatively higher or lower on the surface above it? **Answer** Gravity would be higher above it. However, the higher gravity measurement would not identify the deposit of lead ore or measure its size. Higher gravity might be caused by a small deposit very near the surface or a larger deposit at some greater depth.
6. Does the earth exert a pull on an astronaut in orbit? **Answer** Yes. It is the pull of gravity that keeps the space vehicle in orbit and not shooting off into space. For that matter, earth's gravity is exerted throughout space, but its effect may be cancelled by the pull of another body in space.
7. Place a cube of steel or a stack of steel washers on one of the rock specimens in your classroom. What force holds the steel down? What force holds the steel up? **Answer** Gravity holds the steel down. It is the binding forces between the atoms in the minerals of the rock that holds the steel up. Enough steel would crush the rock, but this would only break the weaker bonding between the mineral grains. The crushed fragments of the rock still would support the steel because of the very strong atomic bonds within the mineral.
8. Does Newton's second law consider force as something which produces motion or something that produces a change of motion? **Answer** The function of a force is to produce a change in motion and not to produce motion. Motion can be accelerated, decelerated, redirected, or stopped only by a force.
9. Suppose that during the reversal of the earth's magnetic field there is a period of years when there is no field at all. What effect might this have on life on the earth? If such a period had occurred in the past, how could earth scientists recognize it? **Answer** Because of the magnetic field a variety of particles radiated by the sun are trapped high above the earth in the Van Allen Belts. Some of these particles would be harmful to life as we know it. Rocks formed during a period of no field would not have the poles of their magnitite grains aligned parallel to each other.

Discussion of unsolved problems

This would be an excellent point in the course to invite an outside speaker to the class. An observatory or a college with an astronomy department may be able to recommend someone who could talk about current research. A television science or weather reporter would be another

possible speaker. Industry often employs scientists whose work would interest the class. You might also check with local chapters of professional scientific societies for speakers.

Answers to questions and problems

A

1. Heat is transferred by the processes of conduction, convection, and radiation. Which of these processes is most effective in each of the examples below: (a) cooling of a cup of hot chocolate, (b) heating a skillet, (c) warming your bed with an electric blanket, and (d) getting a suntan? **Answer** More than one type of heat transfer occurs in each of these cases, but the *most* effective in a and d is radiation; in b and c it is conduction.
2. You have often heard that machines or engines are inefficient — that they waste energy. Does this mean that the energy is lost? Explain. **Answer** No. The energy simply is not available for operating the machine. The law of conservation of energy states that all of the energy can be accounted for.
3. What type of energy is always involved when a substance changes phase? **Answer** Thermal energy is always involved.
4. Why do substances containing radioactive elements tend to become warmer than their environment? **Answer** In the process of radioactive decay, heat is produced within the radioactive material.
5. Since the earth radiates thermal energy, why is it not listed as a contributor to the sun's heat? **Answer** Although the earth radiates thermal energy to space, the *net* transfer of energy must be from the body of higher temperature to that of lower temperature. The sun's surface temperature is very much higher than that of the earth, so the direction of net energy transfer is from the sun to the earth.
6. Is the illumination produced by a lamp a field? Explain. **Answer** Yes. Illumination is a field because it is a region where you can measure light, with a light meter, for example.
7. What force, when acting on a mass of 6 kilograms, will produce an acceleration of 5 meters per second squared. **Answer** F = Ma. $F = 6\ \text{kg} \times 5\ \text{m/sec}^2 = 30$ newtons.
8. If velocity is plotted against time, what does a graph showing accelerated motion look like? uniform motion? **Answer** A graph for accelerated motion appears in Guide Figure 3–6. A graph for uniform motion appears in Guide Figure 3–5A.
9. How is the gravitational force between two objects affected if the distance between them is doubled? tripled? halved? **Answer** If the distance is doubled, the force is one-fourth as great; if tripled, one-ninth as great; if halved, four times as great.
10. If a force of 12 newtons acts on a mass of two kilograms, what will be the acceleration of the mass? **Answer** F = Ma, or

$$a = \frac{F}{M} = \frac{12\ \text{newtons}}{2\ \text{kg}} = \frac{6\ \text{m}}{\text{sec}^2}.$$

11. If the magnetic declination is N 13°E, is true north to the east or west of that direction? Explain. **Answer** True north is west of that direction. Since the compass points 13 degrees east of north, true north would be the direction 13 degrees west of magnetic north.

B

1. List three examples of kinetic energy and three examples of potential energy. **Answer** It is not easy to find examples that apply solely to kinetic or potential energy. Therefore, if the example is primarily one involving motion, it could be classified as kinetic energy. If the example has to do with storage of energy, it could be classified as potential energy.
2. If convection involves the transportation of energy by the material containing it, is the flow of gasoline from the gas tank of a car to the engine an example of convection? **Answer** Although the fuel does carry along energy — stored chemical energy — as it moves from gas tank to engine, the fuel is being moved by a pump. Gravity is not causing its motion; in fact, the fuel pump is working against gravity. Gravity is an essential factor in convection. In addition, the term convection is most commonly applied to the transfer of energy as heat to wipe out differences in temperature. In the fuel line there are no differences in the level of this energy along the path of fuel transport.

3. Is it possible for an object or a substance to contain both kinetic and potential energy at the same time? Explain. **Answer** Yes. Every material contains both kinetic and potential energy. The atoms are in motion and have kinetic energy. The spacing of the atoms represents the storage of potential energy.
4. How does the fact that cold air is denser than warm air aid in the heating of the atmosphere? What would happen to the earth and its atmosphere if warm air were more dense than cold air? **Answer** Because cold air is denser than warm air, it sinks in the atmosphere, thereby forcing the warm air to rise to cooler regions. This process, convection, carries heat upward, causing more of the atmosphere to be heated than would be the case if the process did not occur. If warm air were denser than cold air and did not rise, the atmosphere near the earth would become increasingly warmer. Life as we know it could not exist.
5. What is the value of the gravity field intensity at a distance from the earth's center equal to twice the earth's radius? (Use 9.8 newtons as the value on the earth's surface.) **Answer** Gravity field intensity varies inversely as the square of the distance. If the distance is twice as great, the field intensity is one-fourth as great. Therefore, at a distance equal to twice the earth's radius, the value of the gravity field intensity is 0.25×9.8 newtons $= 2.5$ newtons.

C

1. Trace the heat energy of your body back to the sun as a source. **Answer** The heat produced by the human body results from biological combustion, oxidation, and other chemical changes that convert digested food into thermal energy and products that can be used by the body for growth, replacement, and repair of body tissues. The raw materials for this process, food and oxygen, have been developed through the action of solar energy. Animal life is ultimately dependent on plant life. Almost all plants require photosynthesis to maintain life, and photosynthesis in turn requires sunlight. The oxygen we require has been discharged into the atmosphere by plant life as an end product of photosynthesis. Further solar energy has provided heat to help sustain life all along the food chain.
2. Why does the bathroom floor feel cold though the rug lying on the floor feels warm? **Answer** The floor and the bathroom rug are the same temperature because they are in contact with each other. The floor feels colder because heat is conducted away from our feet faster by the floor than by the rug. The colder feeling from contact with the floor is due to the different conduction rates of the two materials.
3. What term best expresses the quantity of matter? **Answer** Mass is more meaningful than weight in expressing the quantity of matter because the quantity of matter is independent of location. The astronaut has the same mass on the moon as on the earth, but his weight there is much less.
4. In what metric units is the quantity of matter usually expressed? **Answer** Gram and kilogram are the most common units. These terms are also used to express weight. The difference is that mass must be determined on a beam balance, where the unknown can be compared with standard mass units.
5. In these metric terms what is the quantity of matter in your body? **Answer** Determine kilograms by dividing pounds of weight by 2.2 pounds per kilogram. Multiply by 1000 grams per kilogram to find the grams.
6. How big would a cube of granite be that contains the same quantity of matter you do? Describe some important differences between the cube of granite and your body. **Answer** Granite has a density of 2.8 g/cc. The volume of granite in cubic centimeters would be your weight in grams/2.8. Take the cube root of the answer to find the length of an edge of a cube of granite that has the same mass you do. The cube of granite would differ in shape, volume, chemical composition, and atomic arrangement. It would also act differently.

Supplementary Materials

Reference books

Wyllie, Peter J. *The Dynamic Earth.* John Wiley & Sons, New York, 1971. A recent college level text on the dynamics of the solid earth. It covers much of the material in this chapter and in Chapters 11, 12, and 13.

Wilson, Mitchell, *Energy*. Life Science Library, Time-Life, Inc., New York, 1967. A well-illustrated account of energy, its sources, transfer, and uses, written for the general reader.

Bitter, Francis, *Magnets*. Doubleday and Co., Inc., Garden City, N.Y., 1959. (Paperback)

Gamow, George, *Gravity*. Doubleday and Co., Inc., Garden City, N.Y., 1962. (Paperback)

Weisskopf, Victor F., *Knowledge and Wonder*. Doubleday and Co., Inc., Garden City, N.Y., 1963. (Paperback)

Rothman, Milton A., *Discovering the Natural Laws*. Doubleday and Co., Inc., Garden City, N.Y., 1972. (Paperback)

Films

Earth: Its Magnetic Field. 14 minutes, color. Coronet Films.

Gravity: Mighty Pull. 13 minutes, color. Universal Educational Films.

Gravity, Weight, and Weightlessness. 11 minutes, color. Film Associates.

Heat and Temperature. 14 minutes, color, Coronet Films.

Magnetic Force. 29 minutes, color. McGraw-Hill Text Films.

Our Mr. Sun. 60 minutes, color. Bell System TV Science Series.

unit two

The Water Cycle

4. Water in the Sea

Chapter Objectives

After completing the chapter students should be able to:

1. Compare the physical and chemical properties of fresh water and seawater.
2. Describe the processes that change the salinity, temperature, and density of seawater.
3. Explain the causes of surface and deep ocean circulation.
4. Use a model to demonstrate the movement of water particles in surface waves.
5. Trace the path of energy from the sun to ocean waves and currents.
6. Explain how atmospheric circulation and varying densities of seawater cause ocean circulation.

Teaching the Chapter

Chapter 4 does not attempt to cover the full scope of oceanography, but focuses on the role of the ocean in the water cycle. The chapter considers how the sun, wind, gravity, and man's activities interact with the ocean's water.

Much of the material in this chapter will not be new to students, since they have looked at water and splashed around in it long before this course. The aim of the activities is to enable students to observe water under controlled conditions. One technique that may be new is using another material as a model for what happens in water. This approach is used to investigate the Coriolis effect and the motion of particles in a wave.

Suggested time required

It should take four to six days to discuss the topics and complete the investigations in this chapter.

Section Notes

4–1
The water cycle makes the sea salty.
4–2
Materials dissolved in seawater

Not all of the dissolved materials in seawater come from the land. Some elements — boron, chlorine, and sulfur, for example — occur in concentrations far greater than can be accounted for by weathering. The amount of boron that could have been leached from the land is 1/10,000 the amount actually found in the oceans. Can your students suggest any other ways elements can be added to seawater? One explanation is that these over-abundant ions are a result of volcanic activity in the sea. All three elements are common in volcanic gases.

An interesting problem results from the information in Figure 4–3 about the amounts of sodium and potassium ions in seawater. Rocks in the crust contain more potassium than sodium. Both are very soluble in water. However, the amount of potassium dissolved in seawater is much less than the amount of sodium. How could this happen? What factors or conditions could explain this situation? Students are not expected to come up with the right answer, but to propose ways that ions can be removed from seawater. In this case, many of the potassium ions are removed from seawater by the formation of clay minerals. Most of the sodium ions remain in solution. Other materials are removed from seawater by plants and animals.

Demonstration Students should recognize that the *relative* proportions of the most plentiful ions in seawater do not vary. Students may confuse constancy of proportion with variable salinity. Explain that the most variable component of

seawater is the water itself. You can illustrate this principle on the chalkboard or in a demonstration by having the students think of ions as colored grains of sand. For example, imagine that you have a mixture of 10,000 white grains and 1000 red grains in a liter of water. Stir the water and remove a 10 milliliter sample. You would expect the sample to contain about 100 white grains and 10 red grains. If the mixture had been evaporated down to 500 milliliters before taking a 10 milliliter sample, this sample should contain 200 white grains and 20 red grains. If a second liter of water were added to the original mixture before taking a 10 milliliter sample, you would expect the number of white and red grains to be 50 and 5. The *number* of grains in the sample depends on how much water has been added or removed, but in all cases the proportion of white grains to red remains constant at 10 to 1.

4–3 The sea and atmosphere exchange matter and energy.

You might show the film *Sea Surface Meteorology* at this point. The film illustrates how salt particles get into the atmosphere, how raindrops form, and how water vapor receives its electrical charge. It is listed under Supplementary Materials at the end of the chapter.

Action Students can try this at home. As the water in the glass or bottle is warmed, they will observe bubbles forming, rising to the surface, and escaping. A water sample that has been in contact with the atmosphere for some time, or one that has been shaken vigorously, will be nearly saturated with atmospheric gases. Because the solubility of gas decreases as the water temperature is raised, some of the dissolved gases come out of solution and form bubbles on the sides of the glass.

Ask students to look at Figure 4–5 and explain why the net transfer of water from ocean to atmosphere is less at the equator than at 20 degrees north or south latitude. Two reasons that may be familiar are: (1) there is heavy precipitation along the equator, and (2) evaporation is less because the atmosphere at the equator is generally calmer. This is important because the rate of evaporation also depends upon the amount of surface area. Point out that a wavy surface has a greater area than a smooth surface. The surface area of spray droplets and air bubbles are all part of the sea-air interface. The surface area of a stormy region may be 10 times greater than the same region on a calm day.

Action The latent heat of evaporation of alcohol is less than that of water, but alcohol evaporates faster. This increases the cooling effect. Moving air over both hands increases the potential for evaporation and causes even more cooling. Since the energy needed for evaporation is transferred from the skin to the liquids, the temperature of the skin is lowered.

Answers to thought and discussion

1. How does energy from the sun change sea water? **Answer** The temperature of seawater increases when it absorbs energy from the sun. Convection carries the warmed surface water downward and distributes the heat. The sun also provides the energy to evaporate water from the surface of the sea. In regions where evaporation exceeds precipitation there is an increase in the salinity of the sea.
2. Why is the composition of sea salt so different from the composition of the earth's crust? **Answer** Once they reach the ocean there is no way for sodium ions and chloride ions to return to land. These two ions make up the bulk of sea salt. Neither the sodium ion nor the chloride ion is used by marine organisms. In addition, sodium chloride salt is so soluble that it never precipitates onto the sea floor (like the calcium carbonate in coral reefs).
3. Why is the sea-air exchange of carbon dioxide and oxygen crucial to life on the earth? **Answer** If carbon dioxide and oxygen couldn't pass freely between the air and the sea the balance of the gases in the atmosphere would change. Scientists don't know just how it would change, but the balance of the two gases controls the vital life processes of metabolism and photosynthesis. The atmosphere's gases also screen harmful radiation from the earth's surface.
4. What happens to most of the energy coming from the sun? **Answer** Most of the energy goes out into space. Most of the energy that

reaches the earth heats the sea and atmosphere. This causes the great circulation systems of air and water.

4–4
Waves carry energy.

If you can, show the film *Waves on Water* before beginning discussion of this section. It contains good descriptions and demonstrations of various characteristics of water waves.

Call the students' attention to a wave's ability to transfer energy without moving much mass around. Water waves, however, do transfer some mass and thus have momentum. Because wave motion is not limited to water waves, you might compare water waves to what students know of sound waves.

Demonstration A wave or ripple tank is a convenient way of demonstrating the principles of wave motion. Borrow a ripple tank from a high school physics laboratory or build your own. Instructions for construction and use of a ripple tank are given in the *Geology and Earth Sciences Sourcebook.* (See Supplementary Materials.)

Action This activity can be made more sophisticated by substituting the long springs and slinkies used in many physics classes. Springs can show longitudinal as well as transverse wave motion. The rope moves only in a vertical direction, not horizontally along the path of the wave. The knot will have the same motion as the rope; it does not move with the wave. A rope or spring model approximates the motion of water particles in waves because the particles do not move in the direction the wave is going. They move in circles around a point.

4–5
Winds cause currents at the ocean's surface.

Demonstration Students can observe the effects of wind on water by watching the surface of small ponds and puddles. They can observe these effects in the classroom by carefully putting a drop of ink on top of water in a shallow pan and gently blowing across the surface.

Demonstration Use an electric fan and a tank or the plastic box from the Contour Model Kit to illustrate the transfer of momentum across the sea-air interface. Fill the tank with water and direct the airstream across the surface. If you sprinkle some water-soaked sawdust on the water or drop some ink at various points, it will make the movement more obvious. A few small crystals of potassium permanganate work well. As the crystals sink to the bottom of the tank, they leave a purple streak which moves with the current. Watch for places at the ends of the tank where sinking and rising occur. By varying the speed of the fan, you can use the demonstration to show differences in wave formation, current structure, and surface mixing.

4–6
Investigating the Coriolis effect

Time requirements

Pre-lab	10 minutes
Lab	10–15 minutes
Post-lab	10 minutes

Materials

The following materials will be needed by each group of two or three students:

- Coriolis Effect Kit, or:
  - Circular tray or large pie tin
  - Turntable
  - Sand, 100–500 ml
  - Steel ball, 1–4 cm diameter
  - Ramp, at least 5 cm long

Pre-lab discussion

You might bring to class a newspaper map showing the path of a hurricane or damaging storm that passed over North America recently. In most instances, the paths of these storms are curved. Mention that in some cases the curved paths are caused by the earth's rotation.

Notes on procedure

Let the students go on this one. They should be able to answer all questions after several minutes of changing the speed of the tray and the direction of the ball. Some teachers have had success with this investigation by discussing the questions as the students move through the procedure. If you use sand, have a broom and dust pan on hand to take care of spills.

Range of results

Students should find that the faster the turntable is rotating, the sharper will be the curve in the path of the ball. When the tray turns counterclockwise, the ball curves toward the right, no matter what direction it was going when it left the ramp. When the tray turns clockwise, the ball curves leftward.

Post-lab discussion

Use the answers to the questions to develop the reasons why the earth's rotation affects the directions of winds and ocean currents. After that, ask the class what would be different if the earth rotated twice as fast, or not at all. The Coriolis effect on the winds is discussed in Sections 6–7 and 6–8.

Answers to questions

1. Is the ball deflected from a straight path everywhere on the tray? **Answer** If the tray is rotating, yes.
2. Does the direction of deflection depend on which way the ramp is pointing? **Answer** No, the direction of deflection depends only on the direction of rotation.
3. Why doesn't the ball roll in a straight line when the tray rotates? **Answer** Sight along a wall or the table edge and you will see that the ball *does* move in a straight line. Since the tray moves beneath the ball as it rolls, the path of the ball is curved relative to the tray.
4. If the ball were an airplane and you were its pilot, how would you fly a straight course? **Answer** To fly straight relative to the earth, your actual path should curve to compensate for the rotation that takes place while you are airborne. The direction of the curve, however, would depend on whether you were flying in the Northern or Southern Hemisphere.
5. Suppose the tray now represents the Southern Hemisphere. Which way should you turn it, clockwise or counterclockwise? **Answer** Clockwise.
6. How are moving objects in the Southern Hemisphere affected by the earth's rotation? **Answer** The curve points in the opposite direction from the Northern Hemisphere curve. In the Southern Hemisphere the deflection is toward the left.
7. Which ocean currents shown in Figure 4–15 seem to be especially influenced by the Coriolis effect? **Answer** Currents in the Indian Ocean and the north and south Pacific and Atlantic Oceans go where you would expect from the Coriolis effect. There, no land masses break up the current.

4–7
Investigating currents

Advance preparation

You will need a supply of ice.

Time requirements

Pre-lab	5 minutes
Lab	30–60 minutes
Post-lab	15 minutes

Materials

The following materials will be needed for each group of two students:

Plastic column from Plastic Column Kit
Stopper or cap from Plastic Column Kit
Ring stand and clamp
Test tubes, 2
Heat source
Beakers, 100 ml, 2
Transparent box from Contour Model Kit
Thermometers, range −20°C to 50°C, 3
Thermometer, range −10°C to 110°C
Paper cup or plastic bag
Crushed ice, 200–300 ml
Hot water
Table salt
Food coloring

Pre-lab discussion

The Text says that density differences cause deep ocean circulation. You might ask students what could cause these density differences. How might density differences cause water to move?

Notes on procedure

Some teachers have great success making this investigation completely open-ended. If you wish to try it, simply make the materials available to the students. Ask them to investigate how changes in temperature and salinity can affect the density of water.

Encourage different groups to use different concentrations. Any ratios that they choose will give them data to work with. Add food coloring to the salt solutions to make them easier to see. Have the students set up their columns as illus-

trated in Figure 4–17. If students fill the sloping tube too full of fresh water, it may overflow when the salt water is added.

Two factors affect the density of salt water: temperature and salinity. Let the students reach this conclusion on their own. They can increase the density of salt water either by cooling it or by evaporating some of it. Evaporation increases salinity just as adding salt would, since both processes increase the amount of salt in a given quantity of solution.

To complete the evaporation in the time allowed, students will probably need to heat their solutions. They may use a burner, hot plate, or strong light source. If a heat source is not available, have the students leave the solutions uncovered overnight in a warm place.

If students want to add ice to cool their salt solutions, remind them that they are to increase the density of the solution *without* adding anything. A container of salt water can be cooled by holding it in an ice water bath.

In the last part of the investigation, the thermometers may have different initial temperature readings. This may confuse the students until they realize that it is temperature *change*, not absolute temperature, that is important to the investigation.

If you want to suggest an additional investigative activity to students, ask which factor, temperature or salinity, has the greater effect on the density of sea water.

Range of results

The rates the two solutions travel down the tube will depend on the salinity, but the denser solution will always move more rapidly.

The thermometers in the model ocean should show successive drops in temperature. The students should notice that the thermometer nearest the ice starts to drop first, followed by the others.

The food coloring should indicate an underwater current moving away from the cold end. If they let the currents develop long enough, they will see surface currents move toward the cold end of their model ocean. It usually takes about 15–20 minutes for the total circulation pattern to develop.

Post-lab discussion

The students should conclude that as a fluid becomes denser than its surroundings it will sink. Any method that leads them to this conclusion is acceptable. Discuss the results of each part of the lab and ask the students how each of the processes they observed could operate in nature. They may cite examples of currents and water mixing at the mouth of rivers such as the Mississippi. Did the different solutions become completely mixed as quickly as the students expected?

Answers to questions

1. Which solution traveled down the tube faster? **Answer** The solution with the greater density.
2. What processes in nature could cause differences in the density of seawater? **Answer** (1) The evaporation of water from the ocean leaves it saltier and with a higher density. (2) Rain falling on the ocean dilutes it and decreases its density. (3) Cooling makes the ocean more dense and heating makes it less dense. Students might also mention the compression of water in deep parts of the ocean. The effect of compression on liquids, however, is negligible.
3. What kinds of energy transfer did you notice? **Answer** Conduction of heat from water to ice, convection and conduction through the water, and conduction from water to the thermometers. Radiation occurs in every part of the system, but the students have no way of detecting or measuring the effect of radiation.
4. If you observed evidence of currents, what was the evidence and how did the currents behave? **Answer** The evidence is the motion of the food coloring. The successive drops in temperature could be evidence of either convection or conduction. The current moves down from the ice and away from it along the bottom. Students may even see the current curl up and turn back toward the ice when it has reached the far end of the container.
5. What caused the currents? **Answer** The currents were caused by the differences in density in the liquid.

4–8
Density differences and deep currents

For students who become interested in the use of oceanographic instruments, you could plan a visit

to an oceanographic laboratory. If this is difficult at your school, you can show the film *Challenge of the Oceans* instead.

Demonstration Half fill a sloping tube with very dense, clear salt water. Then carefully pour clear fresh water on top of the salt water until the tube is nearly full. Pour in a test tube of colored salt solution with a density less than that of the solution in the bottom of the sloping tube. The colored material will sink through the fresh water and stop when it reaches the denser salt solution. Ask the students to explain what they observe.

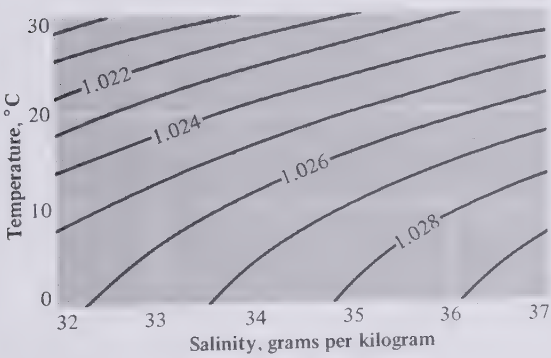
A transparency of Guide Figure 4–1 will help you show that temperature and salinity affect the ocean's density almost equally. In warm tropical regions, salinity varies only slightly with increasing depth. The density increase with depth is due mainly to the accompanying temperature decrease. In cool Arctic and Antarctic regions the temperature variation with depth is relatively small. Salinity increases sharply with depth, however, and is mainly responsible for the corresponding decrease in density.

Folger's map in Figure 4–14 shows the general features of the Gulf Stream reasonably well. This average current meanders about, constantly changing position. (See Figure 4–21.) The stream that usually appears on charts is obtained by averaging these meanders over a long period.

Answers to thought and discussion

1. Where do waves obtain their energy? **Answer** From the wind.
2. How does wave motion change when waves enter shallow water? **Answer** The forward speed of the wave decreases, and the circular movement of water particles becomes elliptical near the sea floor.
3. How does the energy from the sun generate ocean currents? **Answer** Heat from the sun warms some regions of the atmosphere more than others. As a result, different regions have different atmospheric pressures. The differing pressures cause the winds that move the oceans. The sun also warms the oceans more near the equator. This causes some ocean currents.
4. What is the source of deep water currents in the ocean? **Answer** Waters of high density form in high latitudes. There, evaporation and low temperatures create cold, highly saline waters. These waters sink to great depths in the seas and move as deep sea currents.

GUIDE FIGURE 4–1
The density of seawater varies with the temperature and salinity.



Discussion of unsolved problems

The way you discuss ocean pollution with your students is critical if they are to judge the problem objectively. Students must be able to distinguish, for instance, between ocean pollution and the pollution of lakes, rivers, estuaries, and lagoons. One reason the problems should be thought of separately is that the ocean is so much larger. It takes very much longer for any change to have an effect.

Statements such as "a mid-ocean desert," "a 40 per cent decline in living populations," and "an oil film spreading over the world's oceans" have all been made without the benefit of analyzed samples from many different areas of the sea. In 1970 a group of oceanographers searched the scientific literature and discovered that there was not enough information from the ocean to back up any claims for or against ocean pollution.

Soon after, an ocean sampling program was started by the Office for the International Decade for Ocean Exploration in the National Science Foundation. The program was called *Baseline* because it set out to determine the present condition of the ocean. Future changes in the ocean could be evaluated against this information.

Precise measurements were made of the metals mercury, cadmium, lead, copper, and zinc. The water was also analyzed for various man-made compounds such as DDT, DDE, DDD (all

chlorinated hydrocarbons), and PCB (polychlorinated biphenol).

They found no evidence that oil spills create permanent damage to the ocean environment. An oil spill near shore makes a mess, and changes the shoreline environment by killing birds, animals, and rock-dwelling organisms. Natural conditions, however, appear to have returned two or three years after a spill. In the open ocean, there are some organisms that use hydrocarbons in their life processes. Oil added to the ocean may be eliminated naturally by these organisms if the quantity is not too large.

There was no evidence that DDT or PCB are increasing in the ocean. In fact, most of the analyses found concentrations measured only in *parts per billion*. Off coastlines where agriculture is practiced, DDT levels were much higher. Levels were about one part per million for about 200 miles from the coast.

The scientists also discovered that certain natural organic compounds sometimes are accidentally measured along with DDT. Consequently, reports of DDT in various plants and animals far distant from farming areas (the Arctic and Antarctic, for instance) may be incorrect.

There was no evidence of unnaturally high concentrations of heavy metals in any part of the ocean food chain. Even in the more polluted waters of the North Sea and off New York, the levels of mercury and lead in fish were all below 0.5 parts per million. The scientists concluded that the lead and mercury levels in fish in the open ocean were normal.

There was no indication that organisms higher up the food chain concentrate heavy metals in their bodies. Just the opposite is the case, in fact. This evidence indicates that each animal acquires its concentration of heavy metals from the water, not from eating other organisms.

The conclusions of the study do not mean that there is no need to worry about ocean pollution. Many questions remain unanswered. For example, no one knows if harm is done even by very small concentrations of man-made chemicals.

One good, up-to-date reference on environmental pollution is "Environmental Pollution," in *Encyclopedia of Geochemistry and Environmental Sciences*, by G. Claus and George J. Halasi-Kun (Van Nostrand Reinhold Co., New York, 1972).

Answers to questions and problems

A

1. What is salinity? **Answer** Salinity is saltiness. It is expressed by the number of grams of salts dissolved in one kilogram of seawater.
2. In what ways does seawater differ from fresh water? **Answer** The dissolved materials in seawater affect its density, taste, electrical conductivity, and osmotic pressure. Many other answers are possible.
3. Discuss two ways in which energy leaves the ocean. **Answer** Energy leaves the ocean by long-wave radiation, by conduction, and as latent heat of vaporization. (1) Energy from the sun reaching the sea is in the form of short-wave radiation. The seawater absorbs this energy and reradiates it as long-wave radiation. (2) Energy leaves seawater by conduction through the direct contact of the water with the air. If the water is warmer than the air, heat is transferred to the air. (3) Energy leaves the ocean as the heat stored in water vapor. Heat energy must be supplied to the liquid water to make it a gas.
4. What is meant by the wavelength and period of water waves? **Answer** The wavelength is the distance from one wave crest to the next. The period is the length of time required for successive wave crests to pass a stationary point.
5. Where is most solar energy absorbed in the sea? **Answer** At low latitudes, and generally very near the sea surface.
6. What causes ocean surface currents? **Answer** Ocean surface currents are caused mainly by winds.
7. What causes currents in the depths of the ocean? **Answer** Density differences resulting from the exchange of matter and energy at the sea surfaces.

B

1. How do salts get into the sea? **Answer** Water from the land carries dissolved salts that are leached from the earth's crust into the sea.
2. About how much seawater must be evaporated to obtain 453 grams (1 pound) of sea salts? **Answer** Using an average salinity of 35 g/kg, the amount of seawater required to yield 453 grams of salts is $453/35 = 13$ kilograms.

3. What factors determine the salinity of mid-ocean surface waters? **Answer** The salinity is determined primarily by the local water budget—the balance of evaporation and precipitation.
4. Name several things that are transferred across the air-sea interface. **Answer** Energy, water, salt, oxygen, and carbon dioxide.
5. What is the speed of travel of waves having a period of 6 seconds and a wavelength of 56 meters? **Answer** $56/6 = 9.3$ m/sec.
6. If one-half the radiation striking the sea surface is absorbed in the first meter, and one-half the radiation that passes through the first meter is absorbed in the second meter, and so on, what fraction striking the sea surface reaches a depth of 5 meters? 10 meters? **Answer** The fraction reaching 5 meters is:
   $$\tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2} = (\tfrac{1}{2})^5 = 1/32.$$
   The fraction reaching 10 meters is $(\tfrac{1}{2})^{10} = 1/1024$.
7. What is the relation between salinity and density of seawater? **Answer** If temperature does not change, density increases with increasing salinity of seawater. See Section 4–7.

C

1. How much seawater is needed to yield 453 grams of magnesium metal? **Answer** Magnesium constitutes 3.7 per cent of sea salts. So, using an average value of 35 g/kg of salinity, the amount of seawater required to yield 453 grams of magnesium is
   $$\frac{453}{35} \times \frac{100}{3.7} = 350 \text{ kilograms.}$$
2. Trace the flow of energy from the sun to a wave breaking on a beach. **Answer** Students should be able to cite an energy flow similar to the following: Radiant energy passes through the atmosphere and is absorbed in the ocean. Energy returns from the ocean to the atmosphere as long-wave radiation or latent heat of evaporation to drive the wind. Kinetic energy of the wind generates waves. Waves carry kinetic energy across the ocean to the shoreline, where it is spent in breaking.
3. What are some differences between deep and shallow water waves? **Answer** In deep water, long waves travel faster than short waves. In shallow water, all waves travel at the same speed, which changes only with the changing depth of water. Wave motion in deep water does not extend to the ocean bottom. In shallow water it does. Water particles in deep water waves move in circular orbits, while the particle orbits in shallow water waves are flattened.
4. What causes the Gulf Stream? How was it discovered? **Answer** The winds over the entire ocean cause ocean surface currents, including the Gulf Stream. Benjamin Franklin was one of the first to suggest that the Gulf Stream existed. He felt that such a current could explain the difference in travel time for ships going from Europe to America and vice versa.
5. Are south-flowing currents warm or cold currents? **Answer** They are generally cold currents in the Northern Hemisphere and warm currents in the Southern Hemisphere.
6. What effect has the rotation of the earth on ocean currents? **Answer** It causes ocean currents to be deflected to the right of their direction of motion in the Northern Hemisphere and to the left of their direction of motion in the Southern Hemisphere.
7. How would the speed and frequency of convection currents in the ocean compare with those of atmospheric currents? Explain your answer. **Answer** Because the density of water is nearly 1000 times greater than the density of air (at sea-level pressure), water has much greater inertia. The range of water temperature changes is also much less. Convection currents, therefore, should be weaker in the ocean than in the atmosphere.
8. What determines seawater density? **Answer** Temperature and salinity.
9. How do we know about deep ocean currents? **Answer** Most of the knowledge has come from analysis of temperature and salinity distributions. Sometimes indirect observations can be made by floating something in the current.
10. How can the hypothesis that the densest water in the oceans all comes from the region around Antarctica be tested? **Answer** Checking the temperature, salinity, and density of the surface water in all parts of the oceans against those of Antarctica water might reveal its origins.

Supplementary Materials

Reference books

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Waves Across the Pacific. 20 minutes, color. United States Productions.

Waves on Water. 16 minutes, color. American Geological Institute — Encyclopaedia Britannica Educational Corp.

5. Water in the Air

Chapter Objectives

After completing this chapter, students should be able to:

1. Show how the processes of evaporation, condensation, and precipitation are involved in the water cycle.
2. Describe the energy changes during evaporation and condensation.
3. Explain why both energy and air motions are necessary for evaporation to occur.
4. Calculate the height where clouds will form when the temperature and vapor pressure are known.
5. Identify stable and unstable air masses by the types of clouds in the sky.
6. Describe the two ways cloud droplets form precipitation.

Teaching the Chapter

Chapter 4 introduced the water cycle and described the dynamics of the oceans. The focus of Chapter 5 is on the *physical changes* that occur as water is removed from the ocean and transported to the land. Students discover how energy and air motions are involved in evaporation, condensation, and precipitation.

Almost all of the concepts in this chapter are approached through student activities. Students investigate evaporation, energy flow during phase changes, cloud formation, and the stability of air masses. They also determine dew points and relative humidity.

Convection is discussed in this chapter, but only as a process that takes water vapor upward into regions of lower pressure where it cools and condenses. In later chapters students will discover that convection currents also transport water to the continents. Finally, in Chapter 8, the cycle is completed as the water precipitates over the land and eventually returns to the ocean.

Suggested time required

About ten to twelve days will be required to discuss the topics and complete the investigations in this chapter.

Section Notes

5–1
The water cycle

Students may have difficulty understanding that the model of the water cycle is a simplification. Since most students are familiar with the general model, focus on the various subcycles to emphasize what really happens to water in nature.

One way to discuss Figure 5–1 is to use the transparency master at the end of this Guide. Ask students to locate the numerous subcycles and phase changes. Class discussion should try to determine how important evaporation, condensation, sublimation, and melting are to the cycle. You might ask students what factors control evaporation and condensation. This question would make an easy transition into the following investigation.

5–2
Investigating evaporation

Advance preparation

Cut the sponge into various sizes. Be sure you have at least 20 of one size. When time is limited or when humidity is high, you may wish to use

a 50 per cent water-isopropyl alcohol mixture for the evaporating liquid.

Time requirements

Pre-lab	5–10 minutes
Lab	30–45 minutes
Post-lab	10–30 minutes

Materials

The following materials are needed for each group of two students:

- Balance from Evaporation Kit or any equal-arm balance
- Sponge from Evaporation Kit or any absorbent material
- Plastic sandwich bags
- Transparent plastic sheets
- Light with reflector from Radiation Kit
- Food coloring
- Hot water or equipment for heating water
- Graph paper
- Isopropyl alcohol (optional, see Advance Preparation)

Pre-lab discussion

Challenge the students to think of factors that may affect the evaporation rate of water or other liquids. Which factor would have the greatest effect? Ask one or two groups how they plan to investigate. If the question of a control comes up, ask students how they plan to investigate only one factor at a time. Avoid a lengthy discussion because the post-lab discussion will center on the use of controls.

Notes on procedure

To speed the evaporation process, use a more volatile solution, such as the alcohol mixture suggested in the advance preparation. Circulate among the student groups to check their progress. If a group bogs down completely, you could ask them which factor brought up in the pre-lab discussion they would like to investigate. Show them the equipment and make several suggestions, such as fanning or adding heat to one of the sponges. Be sure to give the group several options so that they can choose what they will investigate.

It is difficult to get quantitative data with the balances from the Evaporation Kit. Frequently the balances will stay balanced until the difference is so large that one side drops all the way down. However, you can ask students to rank the importance of each factor. One way to do this is to measure the length of time required for the balance to shift positions.

If the students put too much liquid on their sponges, the excess will drip onto the table or floor. Ask them if they think this dripping will affect their results. You might have a group, perhaps one that bogged down, investigate the effect of using extra liquid.

The students should think of many ways to investigate the factors that affect evaporation, for example:

1. Shine a light on one sponge.
2. Use hot water with one sponge and cold water with the other.
3. Put a closed plastic bag around one sponge.
4. Shine the light on both sponges but put a transparent sheet between one sponge and the light.
5. Use sponges with the same mass but different shapes.
6. Fan one of the sponges.
7. Investigate the same factor at different places in the room.
8. Cut one sponge into several smaller pieces.
9. Use sponges of different colors.

Range of results

The class should identify five or six ways to affect evaporation. Some of these may be different aspects of the same factor, like procedures 3 and 6.

Judgments will vary as to which factor is most important. Students may hold the light far away from the sponge and then fan vigorously. If they do this, they may decide that wind is the most important factor. Instead, students may hold the light close to the sponge. In this case they probably will decide that heat is most important.

Post-lab discussion

Ask each group what factors they investigated and record the results on the board. Students should be able to explain how they arrive at their conclusions. If there is disagreement between groups, have the students compare their methods and try to resolve any differences.

It probably will become clear from the discussion that students often tested two or more variables at once, such as hot water and light. In these cases, the results will not be conclusive because students cannot determine from the investigation the relative importance of any one factor. When this situation comes up, discuss the importance of controls. After the discussion on controls, some of the groups may want to plan their procedure again. Let them find a time to do the investigation over and add their revised data to the results on the chalkboard.

If groups have graphed their results, use the graphs to help decide which factor has the greatest effect. When you go over the answers to the questions, be sure that students have data that supports their conclusions.

Answers to questions

1. What factors influence the rate of evaporation? **Answer** The three factors that have the greatest effect on evaporation are the amount of energy added, the amount of surface area, and the relative humidity in the surrounding air. Students will give other answers, but they will be variations of these three.
2. Which of these factors has the greatest effect? **Answer** Usually student results show that heat (energy) has the greatest effect. In certain cases, when groups have not investigated all factors, they will have data that shows surface area or some other factor has the greatest effect. Therefore, the answer to this question must be based on class results rather than individual results.
3. How do these factors operate in nature? **Answer** The energy from the sun usually is the dominant factor. Winds, surface area, and texture also influence the overall evaporation rate. These factors rarely operate independently.

5–3 Investigating energy changes during evaporation

Advance preparation

Ice is needed for this investigation. Use a styrofoam cooler or arrange to have ice available.

Time requirements

Pre-lab	5 minutes
Lab	25–30 minutes
Post-lab	10–15 minutes

Materials

The following materials are needed for each group of two students:

- Beaker, 150 ml or larger
- Thermometer, range −10°C to 110°C
- Ring stand with ring clamp and wire gauze, or a tripod
- Crushed ice, enough to fill the beaker
- Bunsen burner, alcohol lamp, or hot plate
- Graph paper
- Safety glasses (optional)

Special notes

Warn students not to get paper, hair, or clothing near the flame. Some schools require the use of safety glasses by each student with this type of investigation.

Pre-lab discussion

Ask students what will happen to the temperature of a substance if you continue to supply energy. Be sure to point out safety precautions for using the heat sources.

Notes on procedure

Have students set up the equipment as shown in Figure 5–3. The ice mixture must be stirred constantly, but warn students to stir gently so they won't break the thermometers. Students should not adjust the heat source during the investigation. Make sure it is hot enough to boil the water before students begin. If you have more than two students in a group, have one of them start graphing the results.

Remind students to record the exact time of each reading. If someone misses a reading, the group should continue to record the remaining data and plot it on the graph.

Range of results

The students' graphs should show two rate changes, one just above 0°C, when the ice has all melted, and the other at the boiling point. Keep in mind that the boiling point will change with altitude. Above sea level, students will find that

the boiling point is below 100°C. A student's graph made in Boulder, Colorado, is shown in Guide Figure 5–1. Boulder is approximately 1650 meters above sea level.

Post-lab discussion

Begin by comparing the graphs made by each group. You might have one group put their graph on the board or the overhead projector. Point out any unusual graphs and have that group explain why they think their results differ.

Analysis of the graphs should reveal that although heat was added at a constant rate, the temperature did not change at a constant rate. Ask students to explain what was going on when energy was being added but the temperature did not change. The heat was used to melt the ice and to vaporize the water rather than to raise the temperature. What happens to energy during melting and boiling is explained in Section 5–4.

Answers to questions

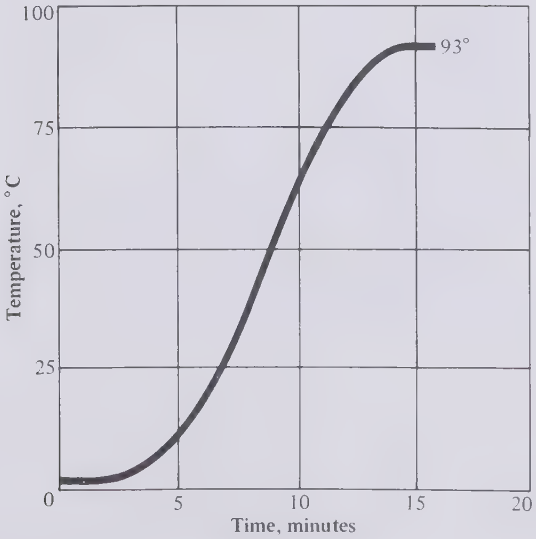
1. How does the energy going into the beaker affect the temperature? **Answer** Adding energy increases the temperature *as long as there is no phase change*. For example, while the ice was melting, the temperature did not change. When all the ice was melted, the temperature began to climb.
2. When did the greatest temperature changes occur? **Answer** The greatest changes occurred when the thermal energy was acting on the water phase alone. This happened after all the ice melted and before the water started to boil.
3. What do you think caused the changes in the slope of the line on your graph? **Answer** At first the energy added to the system was used to melt the ice. During this time, the temperature of the water remained about 0°C. When all the ice melted, the energy went into warming the molecules of the liquid. This caused a sharp rise in temperature although the energy input remained the same. The temperature continued to climb up to the boiling point. At this point, the heat was used in another phase change, from liquid to gaseous water vapor. The temperature of the liquid stabilized a second time near 100°C.

Suggested additional investigations

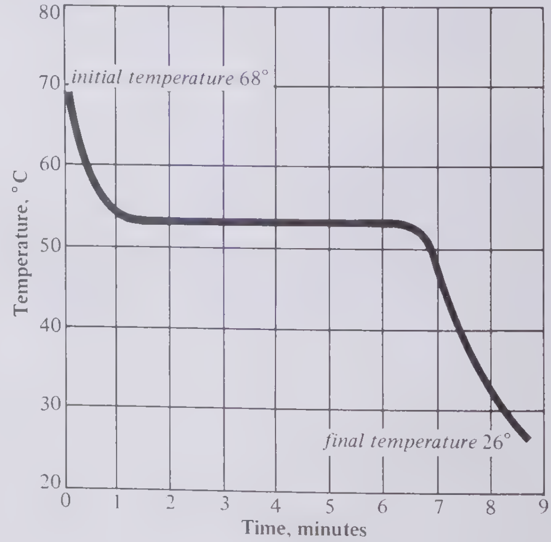
Students could investigate heating or cooling curves for other materials. Mothballs have a cooling curve that makes a good investigation. Place the mothballs in a test tube along with a thermometer and heat in a water bath. Remove the test tube from the water bath when all the mothballs have melted. Take temperature readings every minute until all the melt solidifies. Students should graph and interpret the results. They should resemble Guide Figure 5–2.

Salt solutions of different concentrations give interesting results, especially near the boiling point of the solution. Caution: Be sure not to use flammable liquids for additional investigations.

Guide Figure 5–1
Student graph of Investigation 5–3 for an altitude of 1650 meters.



Guide Figure 5–2
Graph of the cooling of melted mothballs (paradichlorobenzene).



5–4
Melting and boiling

When you discuss latent heat, you can refer students to the graphs they made in Investigation 5–3 and point out the slope changes in the heating curves.

This is a good place to review that temperature is a measure of kinetic energy, while latent heat is stored as potential energy. Some students may ask about the amount of heat absorbed and released during phase changes. If this happens, you may want to discuss with them the Laws of Conservation of Energy and Mass. They should know that a gram of any gas releases the same amount of heat when it condenses as it absorbed during evaporation.

Farmers have sprayed water in the air to protect orchards during spring freezes. From what you know about latent heat, how do you think this might keep the fruit buds from freezing? When the water droplets freeze, the latent heat of fusion is released into the air. The farmers count on this warmed air to prevent the buds from freezing.

Demonstration You can illustrate evaporation and condensation using a large pie pan or some other shallow vessel small enough in diameter to fit under a bell jar. If you cannot find such a pan, make one from aluminum foil. The larger the area of the bottom of the pan, the better the demonstration will work. Mark the side of the pan at heights corresponding to measured volumes of water, say 10 milliliters and 20 milliliters. Fill the pan to the upper mark with tap water. Place it on a flat surface in the sunshine or near a heat source. Cover it with the bell jar but do *not* evacuate the jar.

From time to time, check the level of water in the pan. Ask students what happens to the water level. The water level falls. What happened to the water? It evaporated into the air inside the bell jar. Why did we put the pan in the sun or near a heat source? Raising the temperature of the water increased the energy available for evaporation and also increased the amount of water that the air can absorb. Warm air has a much greater moisture-holding capacity than cold air.

The film *What Makes Clouds?* includes an excellent demonstration of evaporation and condensation.

5–5
Air pressure and vapor pressure

Students have been handling the units of pressure measurement in the Weather Watch. You might review the class procedure for reading the barometer or converting inches of mercury to millibars as part of the discussion of this section.

Many people find it hard to comprehend that pressure inside the body pushes against atmospheric pressure. It may help to mention the example of an astronaut, who wears a special suit in the vacuum outside the spacecraft to prevent his body from inflating like a balloon.

The technical words used in the chapter are defined here for *your* reference. Students need not memorize these definitions.

Adiabatic temperature change The change in temperature of a mass of air when the pressure is changed without adding or removing heat.

Condensation The phase change from a gas to a liquid, always releasing energy to the surroundings.

Dew-point temperature The temperature at which water vapor in the air will start to condense.

Evaporation Changing from a liquid to a gas. Evaporation may occur at any temperature between the melting and boiling temperature. Heat is absorbed by the gas during the process.

Hydrologic or water cycle The movement of water from the ocean to the atmosphere, to the land, and back again to the ocean. This cycle includes a great number of subcycles.

Latent heat of fusion The thermal energy required to change ice at 0°C to water at 0°C. This energy is released as heat when the water freezes again.

Latent heat of vaporization The thermal energy required for the evaporation of water. This energy is contained by water vapor and released as heat when the water vapor condenses. The amount of heat released during condensation is the same as that absorbed during vaporization.

Millibar A unit of pressure equal to 1000 dynes/cm^2. Average atmospheric pressure at sea level is 1013.2 mb. This is equivalent to 29.92 inches of mercury at sea level.

Precipitation Any form of water that falls *from* the atmosphere to the earth's surface, including rain, hail, snow, sleet, and drizzle. Cloud droplets and fogs are not considered to be precipitation.
Relative humidity The ratio of the *actual* amount of water vapor in a volume of air to the *maximum* amount of water the air could hold at that temperature. Relative humidity is expressed as a percentage. Dry air has a low relative humidity, while moist air has a high relative humidity.
Saturation When air contains as much water vapor as it can hold, it is saturated. This condition is 100 per cent relative humidity.
Saturation vapor pressure The pressure of water vapor in a volume of air at 100 per cent relative humidity.
Water vapor Water in the gaseous state. Water vapor is invisible, odorless, tasteless, and mixes freely with other gases in the air. It is less dense than dry air and is formed by the evaporation of liquid water or the sublimation of ice.
Water vapor pressure That portion of the total air pressure that is caused only by the water vapor. The remaining pressure is caused by nitrogen, oxygen, and other gases that make up the air.

5–6 World patterns of vapor pressure

Much of the discussion of this section will center around Figures 5–6 and 5–7. It may help to refer to a globe occasionally. You might ask students how they think water gets into the air from land areas.

You might want to return to Figures 5–6 and 5–7 in Chapter 6. Then you can discuss how the water in the air affects weather at different latitudes.

5–7 Condensation

What condensed moisture looks like and where it comes from will be familiar to most students. You can focus the discussion, therefore, on the causes of condensation. The fact that condensation nuclei are required is likely to be an intriguing new idea. Some students will know about weather modification experiments to produce condensation by seeding clouds with small particles of silver iodide or frozen carbon dioxide. Articles or reports on this topic may interest the class. Many are listed in the Supplementary Materials section.

Demonstration One way to demonstrate condensation is to put a small amount of water in a plastic bag, seal it, and place it in the sunshine. Do this before class. At the start of the class, move the bag to a cool place in the room. Condensation will occur on the inside surfaces of the bag.

Answer to thought and discussion

1. The curves in Figure 5–7 show the difference between evaporation over land and ocean. From your knowledge of geography, try to explain these differences. Why is the maximum evaporation over the ocean near latitude 18 degrees? What causes the dip in the ocean curve near the equator? **Answer** Vapor pressure decreases with increasing latitude because cold air has a lower moisture-carrying capacity than warm air, as shown in Figure 5–6. There is also less energy available for evaporation. Figure 5–5 shows that the evaporation curve over the oceans is generally higher in low latitudes than near the poles. The dip near the equator is produced by the increased cloudiness there. This cloudiness lowers the amount of sunlight reaching the surface and thereby reduces evaporation rates. Another reason for the dip is the very slight air motion in the region called the "doldrums," near the equator.

   The motion of the trade winds in latitudes of 15 to 25 degrees causes the evaporation curve to be somewhat higher than for still air. Thus evaporation rates are related to: (1) temperature of the evaporating surface, (2) temperature of the air, and (3) air motion.
2. Why do you suppose that the maximum amount of water vapor in the air is only about 3 per cent of the total gases? **Answer** The maximum amount of water vapor that can exist in the atmosphere depends upon the maximum temperature. No feasible temperature is high enough to hold more than about 3 per cent water vapor before condensing.
3. The temperature decreases as one goes up into the atmosphere. Above the equator, at a height near 17 kilometers, it plunges to about −112°F. Above that altitude the temperature

increases again. The cold part of the atmosphere over the equator has been called a "trap." How does this cold trap prevent much water vapor from getting into the warmer layer above? **Answer** The cold equatorial tropopause acts as a dehumidifier. The source of water vapor is at the earth's surface. For water vapor to reach the warm upper layer of the atmosphere it must pass through the cold layer. The water vapor cannot do this because it condenses out of the air in the cold. (Cold air can hold less water vapor than warm air.) Clouds do occur in the stratosphere when cyclones and large thunderstorms inject water vapor at other temperatures. These, however, are rare and the stratosphere is *comparatively* free of clouds.

5–8
Observing clouds

Students have been observing clouds as part of the Weather Watch. You might ask them what they learn about the atmosphere in this way. By watching clouds meteorologists can determine the motions of air and the relative amount of water vapor in the atmosphere. Each cloud type suggests a different condition in the atmosphere. These ideas are more important than having students learn the names for the clouds.

You may wish to have your students take pictures of clouds with a camera. The class could then use these photos to distinguish cloud types. They might try to classify the family and type of each cloud photo.

Try to keep the terminology simple. Explain that there are four principal families of clouds (high, middle, or low altitude, and the vertically developed). These families include the two principal cloud types, stratiform and cumuliform. Stratiform clouds are formed in stable air masses while the cumuliform clouds form in unstable, vertically moving air masses. However, the sheet-like clouds in stable air masses may show some small vertical motions.

5–9
Investigating cumulus cloud formation

Advance preparation

Have about 50 milliliters of *crushed* ice available for each group. Call the local weather service for official dew point, cloud height, and temperature readings for that day. Also, check on the condition of the wet-bulb wicks of the psychrometers. If they have been extensively used, the wicks may need replacing.

Time requirements

Pre-lab	5 minutes, if students have used psychrometers for finding dew points 20 minutes, if students are unfamiliar with psychrometric tables
Lab	15–20 minutes
Post-lab	5–10 minutes

Materials

The following materials are needed for each group of two students:

- Shiny metal can from Radiation Kit, or small soup can with label removed
- Sling psychrometer
- Thermometer, range $-10°C$ to $50°C$
- Crushed ice, 50 ml
- Water

Special notes

For best results, the investigation should be done on a day when there are cumulus clouds. If there are no clouds, the investigation can be used to predict the height at which clouds would form if all the necessary conditions were met.

Pre-lab discussion

If cumulus clouds are visible, ask the students how they could determine the cloud height. They probably will suggest several methods of direct measurement. This investigation develops an indirect method of determining cloud height.

Notes on procedure

When students are determining dew points using the metal can, be sure they add the ice in small amounts and stir gently until *all* the ice has melted. Then add another small piece and stir until the dew point is reached. If students add ice to the can of water too fast, the value they get for the dew point will be too low.

In the winter when the room is heated, the temperature and dew point should be measured outdoors. Even in a well-ventilated room in summer, indoor observations usually lead to inaccurate results. You might have different groups of students compare indoor values with outdoor values.

The students use Figure 5–11 to compute the

temperature and dew point for each kilometer of altitude until they find the height where the temperature is below the dew point.

If the students have had algebra, they may use the following method. The temperature at any altitude is found by taking the ground temperature (T_g) minus 10°C per kilometer of altitude (A).

$$T = T_g - (10 \times A).$$

The dew point d for any altitude A is found by taking the dew point at the ground d_g minus 1.7°C for each kilometer of altitude.

$$d = d_g - (1.7 \times A).$$

Since clouds will form when T and d are equal, students can use the equation $T = d$ or $T_g - (10 \times A) = d_g - (1.7 \times A)$.

Solving for A gives the following equation:

$$A = \frac{T_g - d_g}{8.3}.$$

A is then the altitude, in kilometers, where cumulus clouds will form.

Range of results

When data is collected outside, the students can predict the cloud formation height to within a few hundred meters of the height given by the weather service. Data collected indoors usually produces very poor results. In rare cases indoor and outdoor data will be quite different but will give the same value for cloud height.

Post-lab discussion

Compare the altitude the students determined with the altitude obtained from the weather service. Discuss with the students the precision of the equipment, the accuracy of their measurements, and the techniques used. If groups of students collected data both indoors and outdoors, compare the results. Ask students which factors caused the variations. Which data is more valid?

Answers to questions

1. At what height will cumulus clouds form on the day of your observations? (See Figure 5–11.) **Answer** You can check the local weather service for the value that day. You may also determine the temperature and dew point yourself and calculate cloud height.

5–10
Clouds form in the atmosphere.

Demonstration You can illustrate von Guericke's experiment by making a cloud chamber. Use a well-washed, wide-mouth gallon jar such as your school cafeteria might discard. After pouring about a cup of water into the jar, cover the top with an elastic cover made from a good quality rubber balloon or a plastic sheet. Secure the cover by slipping several rubber bands around the threads of the jar.

In a few minutes the water vapor in the jar should be almost saturated. At this point, supply extra condensation nuclei by introducing smoke from a burning match that has just been extinguished. Quickly replace the cover. Wait a few more minutes. Then push the center of the rubber sheet down and hold it there. After a few seconds pull the rubber sheet up, *very suddenly*, well above the mouth of the jar. A cloud should appear if you pull the rubber sheet up quickly enough. See Guide Figure 5–3. Repeat the pro-

Guide Figure 5–3
A cloud forming in a glass jar as described in Section 5–10.

cedure, pushing down and pulling up. The cloud should form in the jar when you pull up and disappear when you push down.

Pulling the rubber sheet up decreases the pressure inside the jar and produces cooling. The *quick* upward pull lowers the pressure and temperature so suddenly that there is no time for heat to flow into the jar. Condensation results because the air is cooled to the saturation or dew-point temperature. Pushing the rubber cover into the jar increases the pressure and, therefore, the temperature. The temperature rises above the saturation temperature and the cloud particles evaporate. The smoke particles in the jar act as condensation nuclei and make it easier for cloud droplets to form.

A very common misconception holds that rising air is cooled because the atmosphere is colder at high levels than near the surface. If that were the case, the cooling of the rising air would be due to conduction. This is *not* what happens. The cooling is the result of the adiabatic expansion of the air.

The topic of *adiabatic* warming and cooling will require special attention but the term need not be introduced explicitly. One of the easiest ways to develop this point is to use an example of air that moves to a different pressure.

Demonstration A bicycle pump or a household insect sprayer with the spray can and tubing removed can be used to demonstrate adiabatic heating. Be sure to hold the pump by the bottom rim so that you do not heat the pump tube with your hand. With the bottom hole open, pump 10 times in about 10 seconds and then feel the lower portion of the pump tube. Repeat this procedure, but hold your finger airtight over the hole at the bottom of the pump. How does the tube feel now? The heat released by compressing the air is enough to show a temperature rise on a thermometer when the bulb is taped to the pump tube. Be sure to discuss frictional heating from the plunger in the pump. Relate the heating to the first part of the demonstration.

To demonstrate adiabatic cooling, use an inflated tube or basketball. Have a student feel the outside of the ball to determine the temperature of the air inside. Then let the air out of the inner tube or basketball. Have the same student feel the air that comes out. If the tube is large enough, there will be a drop of several degrees on a thermometer when the bulb is held in the air stream.

5–11
Investigating an air mass

Advance preparation

Arrange to have a supply of ice, either crushed or cubes.

Time requirements

Pre-lab	5 minutes
Lab	10–20 minutes
Post-lab	10 minutes

Materials

The following materials are needed for each group of two students:

- Air Mass Generator Kit or a hollow plastic cylinder capped at one end, with a smoke inlet near capped end.
- Ice
- Hot water

Pre-lab discussion

Ask the students to refer to the density investigations in Chapters 2 and 4. You might ask the following questions: What effect does density have on the earth's atmosphere? What effects does the density of the atmosphere have upon the environment? Could the density of the atmosphere affect the way you live?

Notes on procedure

If you simply wish to demonstrate the overall effect of temperature on air motions, then students will need very little instruction. One way to make the investigation more quantitative is to have the students compare the temperature of the water to the rate at which the smoke rises through the tube. Then have students graph the data that compares the effect of different temperatures on air currents.

Post-lab discussion

Ask students about experiences that compare to the results of this investigation. Should they live in a heavily industrialized area? Why is the air hard to breathe on cold mornings? How could fog and haze be formed out in the country? What is necessary to change the condition of

unpleasant air in a particular region? How does a fog rise? This investigation is an outstanding example of convection currents in action. You may find it useful to refer back to this investigation when you reach Chapter 7.

Answers to questions

1. Where in the equipment is heat transferred? In what direction? **Answer** The heat transfer is downward, away from the air in the column into the iced water.
2. Does the smoke rise in the cylinder or rest on the bottom? What is the direction of air motion? **Answer** The smoke will come to rest on the bottom of the cylinder. As the air cools and its density increases, it sinks and remains on the bottom of the cylinder. Like the air in the cylinder, the atmosphere also has a stationary lower boundary. Cooling from below tends to stabilize an air mass.
3. In what direction does the air in the cylinder transfer heat? **Answer** The heat transfer is upward, from the hot water into the air.
4. Think about the movement of the smoke. Can you suggest how cumulus clouds might be produced? **Answer** As the air in the cylinder becomes unstable, columns of heated air move upward until the smoke emerges from the top of the cylinder. In the atmosphere, air heated at the earth's surface also pushes upward in columns, forming cumulus clouds in moist air.
5. What kind of air mass would probably have cumulus clouds? **Answer** Air masses heated from below favor the formation of cumuliform or convective clouds. These air masses are unstable.
6. What air mass would increase air pollution over cities and industrial areas? **Answer** Stable air masses allow the accumulation of air pollution. Stable air masses may be produced by cooling from below or by the sinking of air over a large region. Air sinking from high in the atmosphere is warmed (adiabatically) as it is compressed. Thus the air is warm above and cooler below. In either case, there is little or no convection to carry the pollutants away.
7. What conditions help carry pollutants away? **Answer** An unstable air mass—warm below and cool aloft—favors convection and the transport of pollutants away from their source.

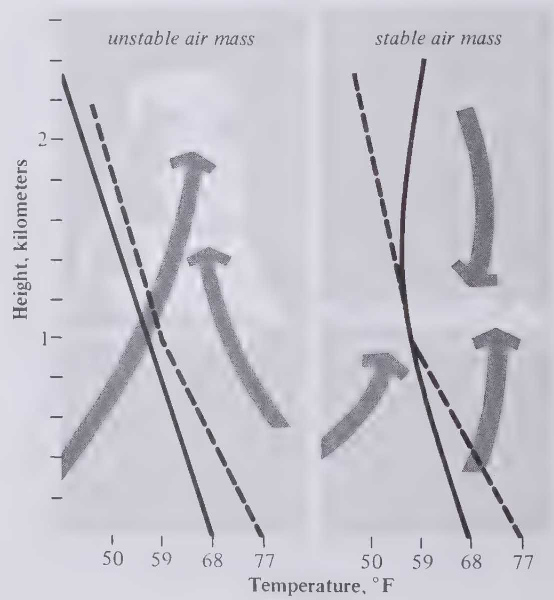
5–12
Why clouds differ

You could show the film *Convective Clouds* at this point. It contains a good demonstration of the effect of air stability on cloud formation. The film is listed under Supplementary Materials at the end of the Guide for this chapter.

You can use a transparency of Guide Figure 5–4 to show the relation between cloud types and the stability of air masses. The temperature of the air is represented by the solid lines in both diagrams. The temperature of each air mass is 20°C and they both have the same dew point. However, in the lefthand diagram the temperature aloft is colder than in the one on the right. The dashed lines show the temperature that a rising volume of air would change to if it were heated to 25°C at the surface. Since the moisture content of the two air masses is the same, each volume would reach saturation at the same height.

For heated air to rise, its density must be less than the surrounding air. Therefore it must be warmer or contain more moisture than the surrounding air. The air mass on the left would cool at the 10°C per kilometer rate (dashed line) until condensation occurs. It then cools at a lower rate of about 6°C per kilometer. The air would continue to rise, because it is still warmer than the surrounding air (solid line). *Convective* clouds will form in the air mass on the left.

Guide Figure 5–4
Graphs of cloud formation in stable and unstable air.



The air mass on the right would rise and cool at the same rates, and condensation would begin at the same level. However, it would stop rising when it reached the same temperature as the surrounding air. Because this air mass is stable, condensation would occur in thin layers. *Stratiform* clouds would be found in the air mass on the right.

Students may find it difficult to understand why moist air is less dense than dry air. If you visualize moist air as being a volume of dry air that has some moisture added to it, this addition of mass would seem to make the air heavier. However, this reasoning fails to consider that moisture in the air displaces some of the dry air. The molecular weight of nitrogen is 28 and that of oxygen, 32. When either oxygen or nitrogen molecules are displaced by water molecules, molecular weight 18, the total mass of the air volume will decrease. That is, the density is less because heavy molecules have been replaced by lighter ones.

Ask students to compare atmospheric pressures when the air is dry (a bright sunny day) and when the air is moist (a cloudy or rainy day). The Weather Watch chart can be used for this. Barometric pressures commonly are lower on cloudy, rainy days than on clear, sunny days.

5–13
Observing precipitation

Students should be able to distinguish between the precipitation that comes from stable and unstable clouds. One obvious distinction is the slow, steady precipitation from stable, layered clouds compared to the sudden, sharp showers from vertically-developed, unstable clouds. Also, steady rain falls in small drops while sudden showers fall in much larger drops that probably form when those smaller drops collide and adhere to one another. This contrast can also be made between small and large snowflakes.

Students might be interested in calculating how much an inch of rain over a specific area weighs. This figure comes to over 113 tons per acre, or 72,300 tons per square mile. Find the area of your state, for instance, to see how many tons of water must be lifted into the air before an inch of rain could occur.

5–14
How are raindrops formed?

The film *The Formation of Raindrops* illustrates the processes and conditions that cause precipitation. It is listed at the end of this chapter.

Demonstration Display a volleyball (diameter 25 cm), a rubber ball (diameter 2.5 cm), and a BB (diameter 0.25 cm). These three spheres represent, respectively, a raindrop, a drizzle drop, and a cloud droplet, each expanded 1000 times.

Cloud droplets are too tiny to be seen individually and they do not fall. Drizzle drops are barely visible, and they do not seem to fall. A 0.025 centimeter raindrop will just begin to fall. How many cloud droplets would be needed to make a drizzle drop? 1000 cloud droplets. How many cloud droplets would be needed to make a small raindrop? 1,000,000 cloud droplets. Can you suggest how these cloud droplets can combine to form a raindrop? If the droplets collide, then they can combine.

Demonstration You can demonstrate the formation of precipitation by diffusion by substituting very fine salt crystals for the ice crystals. Grind some ordinary noniodized table salt until it is powdery. Place a small mound of powdered salt, about the size of a drop of water, one millimeter away from a drop of water on a microscope slide. Place the slide in a microscope or microprojector and have the students observe what happens to the water.

The students see the pile of water gradually disappear while the mound of salt gradually becomes a mound of salt water. The water diffuses over to the salt. In a similar way, liquid droplets in a cloud collect on ice crystals or dust particles until they are too heavy for the support given by the rising air. They then start to fall. The demonstration is not an exact analogy because it involves chemical processes that are not involved in producing natural precipitation. However, some salt particles in the atmosphere do act as condensation nuclei.

Answers to thought and discussion

1. Meteorologists can make some cumulus clouds grow very rapidly by dropping silver iodide particles into the cloud tops. The silver

iodide particles serve as nuclei on which ice crystals can form. In effect, the experimenters are turning part of the water cloud into ice. The meteorologists point out that this change of phase makes the cloud warmer and causes it to develop. Explain how this can happen. **Answer** When ice crystals form, the latent heat of fusion is released and warms the air. If the air in the cloud becomes warmer and less dense than the surrounding air, it will rise. Massive cumuliform clouds result from the condensation of the rising unsaturated air.

2. How is precipitation different from condensation? **Answer** In both cases water collects on an object. Precipitation occurs only when the water drop that has formed grows too heavy to be supported by the air, and falls.
3. If the earth's surface water were all ice, what would the water cycle be like? **Answer** Since water changes from a solid to a vapor over ice, a modified water cycle would exist. Water could leave the ice as vapor, be transported in the atmosphere, and crystallize again on the surface ice. Presumably condensation might also occur in the atmosphere to produce snow.

Discussion of unsolved problems

When you discuss cloud-seeding experiments with your class, point out the key difficulty in evaluating the results: would it have rained anyway? From their experiences with incorrect local weather forecasts, students should realize that meteorologists are unable to predict the exact place and time of natural rainfall.

You could ask your class to guess how people might use the ability to cause rain at will. Agriculture, war, and sports events are a few examples of areas that probably will be mentioned. Who would decide where and how much rain should fall? How would disagreements be settled?

Another topic you could discuss is the relationship some meteorologists believe exists between rainfall cycles and positions of the moon. There is nothing in the nature of ordinary rain-producing forces to explain cyclic variations of rainfall averages over long periods of time. While tidal forces, which vary according to the moon's position, contribute little to the earth's rain-producing mechanisms, their periodicity conceivably could account for the cyclic variations of rainfall averages. Because of the lack of research and evidence, the problem remains unsolved.

Answers to questions and problems

A

1. Describe some of the different pathways in the water cycle. **Answer** Water is diverted from the basic cycle, sea-to-air-to-land-to-sea, by precipitation that occurs over the ocean, evaporation of clouds in the atmosphere, evaporation from the land surface, evaporation of rain from vegetation, storage in lakes and reservoirs, and by plant and animal uptake.
2. Why is temperature an important factor in evaporation? **Answer** Because the saturation vapor pressure depends on the temperature.
3. If the actual vapor pressure is 15 millibars and the saturation vapor pressure is 20 millibars, what is the relative humidity? **Answer** $RH = 15/20 \times 100 = 75$ per cent.
4. What is the main cause of condensation in the atmosphere? **Answer** The rising masses of air that are cooled to the dew point when the air expands.
5. What are the two main processes that start the formation of raindrops in a cloud? **Answer** (1) Diffusion of water vapor from supercooled cloud droplets, and (2) the collision of water droplets in warm clouds.

B

1. The air temperature is 70°F and the dew point is 32°F. About how high must the air be lifted to reach saturation? **Answer** From Figure 5–11, about 2.4 kilometers.
2. A rapidly moving cold front is pushing unstable, tropical, maritime air ahead of it. What kinds of clouds would you expect to find in the air just ahead of the front? **Answer** As the air of the warm sector is squeezed upward by the rapid advance of the cold front, rising motions and scattered cumulus clouds usually result.

C

1. Why do earth scientists speak of *the* water cycle, when water goes through so many dif-

ferent cycles? **Answer** "The water cycle" is a useful expression since it refers to the endless transformations of water from one phase to another. A cycle has no beginning or end, it just keeps going. All the various pathways, major and minor, a water molecule can take through a series of phase changes are lumped in the phrase "the water cycle."

2. The air temperature at the earth's surface is 70°F, and at 3 kilometers it is 35°F. If you could carry a balloon containing air to 3 kilometers, would the temperature of the air in the balloon be warmer or colder than the surrounding air? **Answer** From Figure 5–9, the air in the balloon would be colder than its surroundings.

Supplementary Materials

Reference books

Batton, Louis J. *Harvesting the Clouds. Advances in Weather Modification.* Science Study Series, Doubleday & Company, Inc., Garden City, N.Y., 1969. (Paperback)

Blanchard, Duncan C. *From Raindrops to Volcanoes, Adventures with Sea Surface Meteorology.* Science Study Series, Doubleday & Company, Inc., Garden City, N.Y., 1967. (Paperback)

Davis, Ken, and Leopold, Luna B. *Water* (Life Sciences Library) Time-Life, Inc., New York, 1966. Excellent popular account of the basics of the water cycle.

Middleton, W. E. Knowles. *A History of the Theories of Rain and Other Forms of Precipitation,* University of Chicago Press, 1969. Description of the original experiments may suggest simple demonstrations for the classroom.

Milne, Lorus, and Milne, Margery. *Water and Life.* Atheneum Publishers, New York, 1964.

Riehl, Herbert. *Introduction to the Atmosphere,* 2nd edition. McGraw-Hill Book Co., New York, 1972.

Thompson, Philip C. D., O'Brien, Robert, and the Editors of *Life. Weather* (Life Sciences Library). Time-Life, Inc., New York, 1965. Easily understood overview of the atmosphere and its processes.

Periodicals

Weatherwise: The Magazine About the Weather. (Published bimonthly by American Meteorological Society and others. Circulation office, AMS, 45 Beacon Street, Boston, Massachusetts 02108)

Films

Above the Horizon. color, 20 minutes. American Meteorological Society — Educational Services, Inc.

Convective Clouds. color, 24 minutes. AMS — Educational Development Center, 1971.

The Formation of Raindrops. color, 15 minutes. AMS — ESI, 1965.

What Makes Clouds? color, 19 minutes. American Geological Institute — Encyclopaedia Britannica Educational Corp., 1964.

What Makes the Wind Blow? color, 16 minutes. AGI — EBEC, 1964.

6. Energy and Wind

Chapter Objectives

After completing this chapter, students should be able to:

1. Discuss the importance of the sun's distance from the earth to the natural occurrence of water in the gaseous, liquid, and solid phases.
2. Demonstrate how the earth's shape and orientation in space determine the distribution of incoming radiation.
3. Demonstrate how land and water absorb energy at different rates.
4. Explain how unequal heating of land and water, aided by gravity, produce convective circulation.
5. Make a model that demonstrates how the earth's rotation modifies basic convective circulation to produce easterly and westerly winds.

Teaching the Chapter

To explain the water cycle in the atmosphere, it is necessary to discuss air motions. Chapter 5 described evaporation and condensation and introduced the idea of convection. Chapter 6 expands upon these concepts to establish the basic pattern of global air circulation.

In the beginning of the chapter students investigate radiative balance and the relation to the water cycle of the earth's distance from the sun. They also investigate the temperature differences produced by unequal heating of land and water. The questions students answer focus on the effect of each of these fundamental concepts on the earth's weather.

The chapter includes a brief historical account of the theory of general circulation in the atmosphere. It describes early attempts to explain sailors' reports of wind patterns. Then it shows how later scientists refined the early theories of convection to include the earth's rotation and other factors that affect circulation. With this information about the general circulation, students are prepared to study the role of weather and climate in the water cycle.

Suggested time required

About ten to twelve days should be allowed to complete the investigations and discuss the topics in this chapter.

Section Notes

6–1
Investigating radiant energy

Time requirements

Pre-lab	10 minutes
Lab	20–25 minutes
Post-lab	10 minutes

Materials

The following materials will be needed by each group of three or four students:

- Black metal cans from Radiation Kit or painted soup cans, 4
- Insulating lids from Radiation Kit, 4
- Thermometers, range −20° to 50°C, 4
- Lamp with 200-watt bulb from Radiation Kit
- Meterstick

Special notes

Do not use a light source with a reflector. The reflector will interfere with the results of the investigation by focusing the light toward the cans.

Like the sun, the lamp should radiate energy equally in all directions.

Check to be sure all electrical connections are safe.

Pre-lab discussion

You can start the students thinking about the relationship between the earth's distance from the sun and the phases of water by asking questions such as: How does distance affect energy transmitted from the sun? What would the water cycle be like if earth were closer to the sun? If it were farther away?

When you discuss the setup, ask students in what ways the light and cans in this investigation are analogous to the sun and planets. In what ways are they different?

Notes on procedure

Have the students set up the equipment as shown in Figure 6–1. The cans should arc out from the light in successive increments of a unit distance, d. A value of 20 to 30 centimeters for the unit distance seems to work well. Not all groups should use the same unit distance. Warn students not to have the first can so close to the light that the temperature exceeds the range of the thermometer.

From the temperature rise of the nearest can and the inverse-square relation, students compute what temperature rise should have occurred in each of the other cans. By graphing the computed rise on the same sheet as the actual rise, they can see if the relation between heating and distance is described by an inverse-square curve. The data table in Guide Figure 6–1 should make it clear to the students which data is to be graphed. You could draw one on the chalkboard for a model or make copies to hand out.

Students may have trouble handling the inverse-square relationship. Another way to explain it is to review the concept that an *inverse* relation means that the amount of temperature change *decreases* with increasing distance from the energy source. Or even more simply, the *more* distance, the *less* light. In an *inverse-square* relation the amount of change decreases with the square of the distance.

Range of results

The students will have to find the observed temperature curve OTC by subtracting beginning temperature BT from the stabilized temperature ST of each can. To obtain the theoretical (calculated) temperature changes CTC for cans 2, 3, and 4, the students substitute OTC_1, the observed temperature change at Can 1, into the formula. Since $d = 1$ satisfies the equation for the first can, multiples of this unit distance (2, 3, 4) are then used to compute the changes for cans 2, 3, and 4.

The OTC curve should approximate the CTC curve, which is an inverse-square curve. The

Guide Figure 6–1
Sample Data Table for Investigation 6–1

Can Number	Unit Distance	Actual Distance	Beginning Temperature (BT)	Stabilized Temperature (ST)	Observed Temperature Change (OTC)	Calculated Temperature Change (CTC)
1						
2						
3						
4						

graph should resemble the one shown in Guide Figure 6–2.

Post-lab discussion

Center the discussion around the graph and the students' answers to the questions.

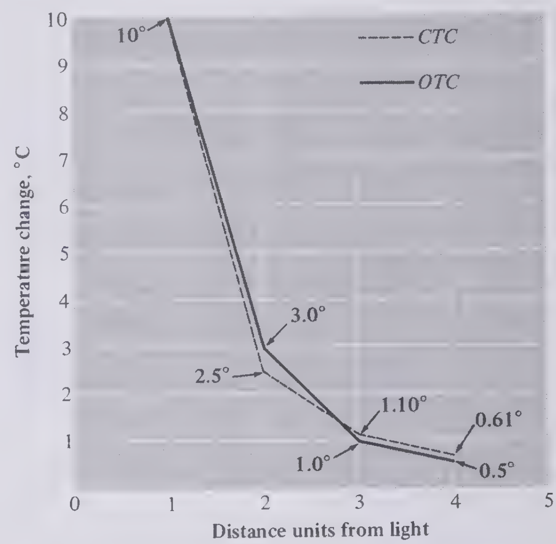
When the temperature of each can is constant (stabilized), the cans are emitting the same amount of radiation they receive. From their observations students should be able to suggest several ways to unbalance the system. The earth's temperature is controlled by the amount of energy it receives from the sun. Is the temperature of the earth stabilized? Does the temperature change from winter to summer mean the earth is emitting more heat, or less?

Guide Figure 6–3 is another way to show that the amount of energy received decreases with increasing distance from an energy source. The change of temperature with distance from the lamp varies as $1/d^2$. You should mention, however, that it is *not* the temperature T, but the difference between the can temperature ST and the room temperature BT, that is inversely proportional to the square of the distance from the lamp. This temperature-distance relation is somewhat different from the variation of planet reradiation temperature with distance from the sun, $1/\sqrt{d}$, illustrated in Figure 6–2.

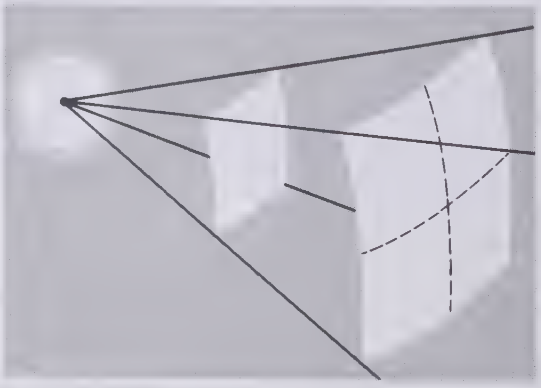
Answers to questions

1. Why did the temperature eventually stabilize? **Answer** As the temperature of the cans increases, the reradiation increases, until they emit the same amount of energy that they absorb from the light.
2. What is the relation between the temperature change and the distance of each can from the lamp? **Answer** The temperature change decreases with increasing distance from the lamp.
3. Do your observed temperature changes agree with those calculated from the formula? **Answer** Quite often, the observed temperature differences will follow closely the theoretical curve. However, heat transfer processes other than radiation will influence the results. Some of these might be reflection from table surface, convection, and conduction.
4. Figure 6–2 shows how the temperatures of the planets decrease with distance from the sun. Would most of the earth's water be solid, liquid, or gas if the earth were one-half its present distance from the sun? Twice its present distance from the sun? **Answer** The earth's temperature would be so high that water vapor would probably saturate the entire atmosphere if the earth were half its present distance from the sun. However, the upper atmosphere would be cool and the vapor would condense to form a dense cloud cover. This in turn would reflect more of the incoming radiation, and the earth's surface

Guide Figure 6–2
Sample graph of calculated and observed can temperatures for Investigation 6–1.



Guide Figure 6–3
The inverse-square law calculates how radiant energy thins out to cover more area as it travels farther away from the source.



would probably be cooler than the temperature computed from the following formula:

$$T = \frac{T_{earth}}{\sqrt{0.5}} = \frac{290°K}{0.7} = 415°K, \text{ or } 142°C.$$

The students are not expected to give such a sophisticated answer, but a brief discussion along these lines will serve to prepare them to understand the effects of water vapor in the earth's atmosphere.

At twice its present distance from the sun, the earth's surface temperature would be below freezing most of the time. Its water supply would be predominantly ice.

The following calculation shows that the average temperature of a planet two astronomical units from the sun would be about 206°K. You can compare this to the freezing point of water at 273°K:

$$T = \frac{T_{earth}}{\sqrt{2}} = \frac{290°K}{1.4} = 206°K, \text{ or } -67°C.$$

6–2
Earth's energy balance and distance from the sun

Ask students to tell from Figure 6–2 what form water would take on Mercury and Pluto. Mercury is so hot that any water there must be in the form of vapor. On Pluto, it would be ice.

There are several points that you may have to clarify for the students. (1) The amount of energy an object receives varies inversely with the square of the distance from the energy source. This idea was used to answer questions in Investigation 6–1. (2) The temperature that any body, a planet, for instance, must have in order to emit a given amount of energy varies inversely with the square root of the distance from the energy source. The curve in Figure 6–2 illustrates this relation. (3) You can refer back to the answer to question 4 in Section 6–1 to emphasize that the calculations used to determine the temperatures of the planets in Figure 6–2 are highly simplified. They are helpful in showing the overall effect, but they are not completely accurate. The temperature of the earth calculated from the formula is wrong because of the gases in earth's atmosphere. The calculations assume that the planets are spherical, rotating black bodies that absorb and emit all the energy they receive from the sun.

Climatic fluctuations do not indicate that the earth-atmosphere system is not in radiative balance. They may indicate variations only in the exchange of energy between the earth and the atmosphere or changes in the percentage of incoming energy that is reflected. Point out that the earth's surface temperature is constant at least twice each day, when the maximum and minimum temperatures are reached.

6–3
The atmosphere and the earth's energy balance

Review the principles of radiative transfer of energy in Chapter 3. You might let students contrast in their own words absorption, transmission, and reflection of radiant energy. Look for familiar examples of each process. Point out, for example, that we can see an object because of the light that is reflected. Thus, clouds, snow, and ice appear dazzling white in direct sunlight. Ask students if they have walked barefooted across asphalt paving in the summer and had to hurry to reach a cool patch of lawn. The grass is cooler because it absorbs and radiates less energy than the asphalt. It also loses heat during transpiration. Why does a piece of metal feel colder than a piece of wood at the same air temperature?

Because of the greenhouse effect nights are warmer in cloudy weather. The cloud cover returns emitted energy to the earth's surface. Research has shown, however, that an actual greenhouse doesn't work that way. A greenhouse seems to keep plants warm primarily by trapping air inside, not because the glass cover selectively absorbs radiation. Thus the term "greenhouse effect" is not completely accurate in describing the role of water vapor and carbon dioxide in the atmosphere. However, the term is commonly used.

Students may be familiar with the names of

the layers of the atmosphere from earlier studies. You might ask students into which layer birds, sub- and supersonic aircraft, satellites, kites, and other items reach. You could assign a list of examples for homework or have the class work it out on the chalkboard.

Answers to thought and discussion

1. Twice each day when the earth's surface is absorbing and emitting the same amount of energy, the temperature is constant for a brief period. Can you relate these temperatures to temperatures in the daily weather report? **Answer** To discuss this question, you should have the local hourly temperature readings for the last 24 hours. It is usually just before sunrise and a few hours after noon that a point on the earth's surface is in radiative balance, emitting and absorbing energy at the same rate. At these times the temperature is neither rising nor falling. When the temperature is rising, incoming radiation exceeds outgoing radiation. When the temperature is falling, the reverse is generally true.
2. What effect would a great increase in the atmosphere's water vapor have on the surface temperature? Would you expect more water vapor if the surface temperature were higher? **Answer** The immediate effect of an increase in atmospheric water vapor would be an increase in the earth's surface temperature. The increased water vapor would absorb more of the infrared, or long-wave radiation from the earth's surface, and reradiate more energy back to the earth's surface, keeping it at a higher temperature. The higher temperature would, in turn, permit more evaporation and more water vapor in the atmosphere. However, more water vapor also could mean more cloudiness, which in turn would reflect more insolation and conceivably lead to a cooling of the earth's surface.

6–4 Insolation and the earth's temperature patterns

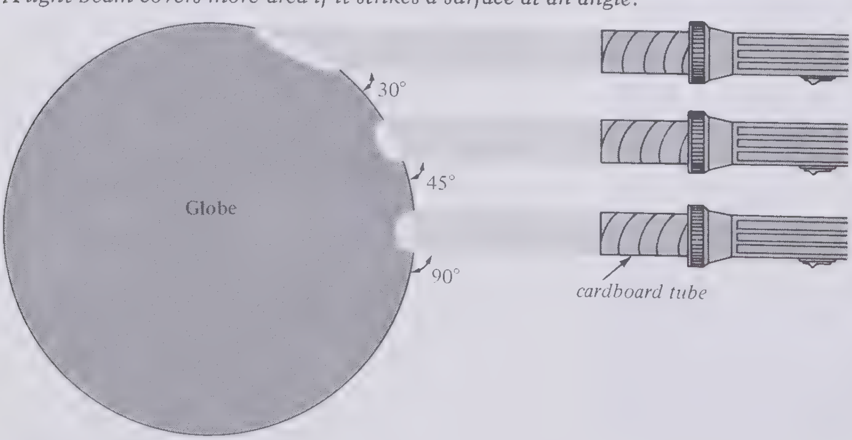
Demonstration You can demonstrate one of the major concepts in this section using a flashlight and a globe. Attach a short paper towel tube to the flashlight as shown in Guide Figure 6–4. When you shine the light on different parts of the globe while holding the flashlight at the same place, students will observe that the same amount of energy is spread over different-sized areas. If you rotate the globe, the light spreads evenly around a circle of latitude during the course of one day.

The demonstration effectively shows how the earth's curvature causes the latitudinal distribution of insolation, the equatorial heat surplus, and the polar heat deficit.

One way to review how the angle of incidence and length of day affects insolation (Figure 6–7) is to refer to the change in temperatures from fall to winter observed in the Weather Watch. Seasonal temperature change is related to the energy budget. Ask the students what the energy budget is at their latitude in July and January. Have them explain their answers. You can also ask how energy is transferred from the low to the high latitudes. Convection of air and ocean currents probably will be mentioned.

The values in Figures 6–8 and 6–9 are *air* tem-

Guide Figure 6–4
A light beam covers more area if it strikes a surface at an angle.



peratures averaged from the daily means for the month shown. The daily mean is computed as follows:

$$\text{Daily mean} = \frac{\text{maximum for the day} + \text{minimum for the day}}{2}$$

The day is the 24-hour period from midnight to midnight.

6–5 Investigating land and water temperatures

Advance preparation

Since the containers for the soil and water may differ in size, shape and material, the success that students have with this investigation may vary. It is suggested that you do the investigation ahead of time with the equipment the students will use to discover any problems with the setup.

Time requirements

Pre-lab	5–10 minutes
Lab	30–40 minutes
Post-lab	10–15 minutes

Materials

The following materials will be needed for each group of three or four students:

- Containers, 500 ml capacity, 2
- Thermometers, range −20°C to 50°C, 4
- Dry sand or soil
- Water
- Lamp, 200-watt bulb with reflector, from Radiation Kit
- Ring stand

Special notes

Observe safety precautions since both water and electricity are involved.

Pre-lab discussion

Ask students to use the temperature patterns in Figures 6–8 and 6–9 to predict the effects of land and water on the amount of energy at the earth's surface. Ask them to predict which can will heat quicker and which will cool faster.

Notes on procedure

Have the students set up the equipment as shown in Figure 6–10. The lamp with reflector should be mounted about 30–40 centimeters directly above the surface of the water and soil, so that they receive equal amounts of radiation. Two thermometers should be placed so that the bulbs are one centimeter above each surface. Bulbs of the other two thermometers are one centimeter below each surface.

Range of results

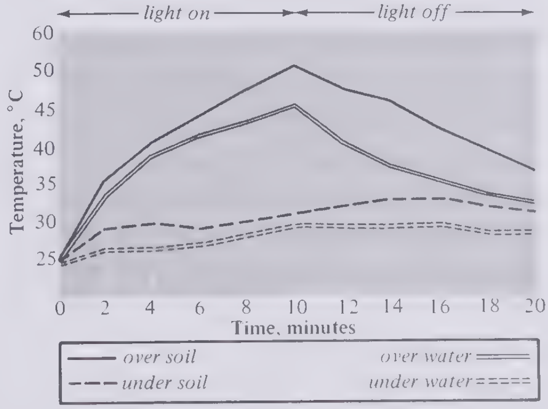
The amount of temperature change will vary if the light source or the location of the thermometers is different from the drawing, but the pattern should be the same. A typical student graph is shown in Guide Figure 6–5.

Post-lab discussion

Section 6–6 can be discussed in conjunction with the post-lab, since they are closely related. Some questions you can ask, for example, are: How do you explain why the temperatures in the investigation varied as they did? What significance do these variations have for atmospheric circulation patterns?

The students' discussion should bring out these major points: (1) A given amount of energy will raise the temperature of land more than water. Similarly, land loses heat energy faster than water does. This causes the air above land to heat and cool faster than the air over water. (2) Water tends to have fairly stable temperatures because it must absorb or lose a large amount of energy for a small temperature change. Water also loses in evaporation some of the energy it absorbs. (3) Large land and water bodies can affect general circulation patterns because of their different responses to incoming solar energy.

Guide Figure 6–5
Sample graph of can temperatures for Investigation 6–5.



Answers to questions

1. Does the air heat up faster over the soil or the water? Why? **Answer** Air over soil heats up faster than air over water because soil warms more quickly than water. The soil conducts and reradiates some of this heat to the air.
2. Why were the rate of temperature change of the soil and the rate of temperature change of the water different? **Answer** It takes more heat to warm water than to warm the same amount of soil.
3. Which received more heat energy from the lamp, the soil or the water? Why? **Answer** Both received the same amount of heat, since the light shone equally on them both.
4. Which lost heat faster, the soil or the water? **Answer** Soil lost heat faster because it is a better radiator of heat. In addition, the rate at which a material radiates heat increases with increased temperature. The soil was warmer to begin with so it radiated faster.
5. The atmosphere gains heat from a heat source and loses heat to a heat sink. Which might be considered a heat source during the winter: soil or water? **Answer** Water would be a heat source during the winter because water stores heat and loses it slowly. Water contains a reservoir of heat after its surroundings have lost theirs.
6. Why do the isotherms in Figures 6–8 and 6–9 bend north and south? **Answer** They bend over the continents. The land areas heat faster than the water areas. They also cool faster.
7. How would you expect air pressure over a warm part of the earth's surface to compare with air pressure over a cooler area? **Answer** Pressure will be lower. The air would be heated by the underlying warm surface and become less dense.

Answers to thought and discussion

1. Because of the earth's round shape and its rotation, the insolation varies with latitude and is distributed equally around latitude circles. Do you think that the amount of energy absorbed is the same all around a latitude circle? **Answer** It would be different. The amount of energy absorbed by the earth and its atmosphere is the difference between the incoming solar energy and the amount of energy that is reflected. Water, soil, vegetation, snow cover, and clouds reflect different percentages of insolation. These reflecting surfaces are not the same around a given line of latitude. Therefore the reflected energy varies, and the amount of energy left over to be absorbed differs.
2. On the average, the low latitudes of the earth absorb more radiant energy than they emit. The high latitudes emit more energy than they absorb. The surplus heat at low latitudes must be transported to high latitudes to balance the earth's energy budget. Can you suggest two ways the energy can be transported? **Answer** The heat is being transferred by both winds and ocean currents.
3. Records show that the entire earth's average temperature is higher during the Northern Hemisphere summer when the earth is farthest from the sun than it is during the Northern Hemisphere winter when the earth is closest to the sun. Knowing that most of the earth's land masses are in the Northern Hemisphere, can you suggest why average temperature is higher when it is farther from the sun? **Answer** During the summer in the Northern Hemisphere, the sun's rays strike the earth more directly than in winter. Since land has a greater temperature change for each calorie of heat absorbed than does water, the entire earth becomes warmer than it does during the summer in the Southern Hemisphere. Then more of the sun's energy goes to heat water. Distance from the sun is not much of a factor, since this varies only from 147×10^6 kilometers in January to 152×10^6 kilometers in July.

6–6
Continents and oceans produce monsoons.

Chapter 5 introduced convection as a method of transferring heat from one place to another. In this section convection is shown to cause major circulation patterns in the atmosphere.

Demonstration A demonstration of convection currents in a tank of water (See Figure 3–7)

can illustrate the atmosphere's basic motions. Both the water in the tank and the air in the atmosphere transfer heat from a warm to a cooler area.

As the circulation pattern develops ask students to think of forces other than gravity that could move air. Fundamentally, gravity is the only natural force that moves the atmosphere. You could ask them: How does gravity, which acts downward, cause horizontal and upward motion in the tank? Call students' attention to the convection currents in the tank of water. Although air moves in direct response to the unbalanced pressure force created by convection currents, the basic force behind this motion is gravity.

The film *What Makes the Wind Blow?* gives an excellent introduction to convection using the sea breeze as an illustration. Ask students how the sea breeze example could apply to the global circulation of air. To flow horizontally over the great distances on the earth, the atmosphere must be heated at one place and cooled at another. Students will be able to apply their observations in Investigation 6–5, as well.

6–7
The trade winds
6–8
World patterns of pressure and wind

The trade winds section focuses on just one aspect of the world wind patterns. It makes a good introduction to Section 6–8, which deals with atmospheric motions in a general way. If you would like an alternate way to explain the Hadley cells, it will be useful to remind students that air in motion behaves much like water. Air, however, is compressible. Its weight compresses the air below it and increases the density of the low atmosphere. At the earth's surface, air flowing or converging toward an area from various directions is forced to move upward. Similarly, when air sinks over an area, it tends to produce outward-flowing currents. Thus *divergence* at the earth's surface is associated with sinking air and *convergence* at the earth's surface is associated with rising air.

Students should have little difficulty applying the technique they used in Investigation 4–6 to the Coriolis effect on wind. It is a good idea to have the Coriolis Effect Kit available and let students work out their own qualitative understanding of the effect of earth's rotation on wind.

The film *The Inconstant Air* is useful in this section. It emphasizes that the atmosphere's general circulation is a result of the rotation rate, the distribution of insolation, and the composition of the atmosphere. The eddies in the rotating pan experiment demonstrate that irregularities in the earth's surface are not essential for cyclones and anticyclones to form. In the pan cyclones develop, mature, and decay just as they do in the atmosphere.

Ask students why there are no clouds over certain areas in Figure 6–17. Have them find evidence for monsoon circulations, and the subsiding air found in the subtropical high pressure cells.

Answers to thought and discussion

1. When air currents near the earth's surface meet or converge, what happens to the air? When air currents flow out of a region or diverge, where does the air come from? **Answer** When air currents converge near the earth's surface, the air must rise. When air currents diverge near the earth's surface, air must sink from the atmosphere above to replace the outflowing air.
2. What causes motion in the atmosphere along the latitude circles? **Answer** The rotation of the earth deflects the winds from what would be a straight path between the equator and the poles.

Discussion of unsolved problems

More weather observations over the entire globe may make it possible to predict the weather several weeks in advance. The World Meteorological Organization, a United Nations agency, is currently developing a World Weather Program using a worldwide network of computers, weather balloons, weather satellites, and communications satellites. Weather satellites already supply cloud and temperature observations for the network.

Measurements of radiant energy at several wavelengths can be made to determine the ver-

tical temperature distribution of the atmosphere. Balloons have been constructed that float at a constant height in the atmosphere for many days. These experimental balloons carry miniature instruments which signal air pressure and temperature data to satellites. The balloons are tracked to determine air motion. Since ordinary instruments present a hazard to aircraft, scientists are developing new instruments that simply shatter on contact with an airplane. The system using these easily breakable instruments is called GHOST, an acronym for Global Horizontal Sounding Technique.

Answers to questions and problems

A

1. If an object is radiating the same amount of energy it is absorbing, does its surface temperature rise, fall, or remain the same? **Answer** It is in radiative balance, and its temperature remains the same.
2. If the earth were twice its present distance from the sun, what would be its approximate temperature? **Answer** From Figure 6–2, about -60 to $-70°C$. (See Investigation 6–1.)
3. How do water vapor and carbon dioxide keep the earth's surface warm? **Answer** Water vapor and carbon dioxide absorb long-wave radiation from the earth's surface, become warm, and emit part of this energy back to the surface. The double path of energy reaching the surface (from both the sun and the atmosphere) causes the earth's surface temperature to be higher than it otherwise would be.
4. If a pan containing water is heated at the rim and cooled at the center, what motion takes place? **Answer** The water rises at the rim and flows toward the center of the pan, where it sinks and flows back toward the rim near the bottom of the pan. Similarly, air rises at the equator, flows north and south, sinks on reaching the poles, and then flows back north and south to the equator.
5. What is a monsoon? **Answer** A monsoon is a circulation of the atmosphere caused by seasonal changes in the heating of the continents and oceans. The monsoon reverses its direction of flow with the seasons.

B

1. Can you show how temperature differences can produce horizontal pressure differences in a fluid? **Answer** When a fluid is warm at one place and cool at another, the density of the cold section is greater than that of the warm section. The colder fluid sinks closer to the bottom surface and the warm fluid flows in on top of the cool fluid. This movement decreases the pressure in the warmer section. The cooler fluid then flows toward the warm section across the bottom.
2. Where on earth would you expect to find the greatest annual range of temperatures? **Answer** The greatest annual range of temperatures should occur near the center of the largest land mass at a high latitude.

C

1. Explain how the dimensions of the atmosphere are related to the air's patterns of motion, namely, vertical cells and horizontal eddies. **Answer** Since the vertical dimensions of the atmosphere are quite small when compared with its horizontal dimensions, only small-scale motions can be as high as they are wide. These small-scale motions, when they complete a closed path, are usually referred to as vertical cells. Large-scale motion patterns, on the other hand, are much wider than they are high and are called horizontal eddies.
2. When the air is very dry, the temperature just before sunrise tends to be lower than when the air contains a lot of water vapor. Can you explain why? **Answer** When air is dry, less water vapor is present to absorb the radiation from the earth's surface. Thus, more long-wave radiation escapes through the atmosphere. Less energy is turned back toward the earth's surface than when the air contains a lot of water vapor.

Supplementary Materials

Reference books

Blair, Thomas A., and Fite, Robert C. *Weather Elements*, 5th ed. Prentice-Hall, Inc., Englewood Cliffs, N.J., 1965. Nonmathematical,

first-year-college text good for general background.

Hare, Fredrick K. *The Restless Atmosphere.* Harper & Row, Publishers (Torchbook), New York, 1961. (Paperback) Popular treatment of general meteorological problems.

Strahler, Arthur N. *The Earth Sciences,* 2d ed. Harper & Row, New York, 1971. Excellent up-to-date discussion of atmospheric circulation.

Sutcliffe, Reginald. *Weather and Climate.* World Publishing Co., New York, 1969. (Paperback) Excellent for background on general circulation.

Thompson, Philip D., and O'Brien, Robert. *Weather.* Time-Life, Inc., New York, 1965. Highly recommended portrayal of weather and its effects.

Periodicals

Weather. Royal Meteorological Society, London. Popular British weather magazine.

Weatherwise. American Meteorological Society, Boston.

Films

Above the Horizon. 25 minutes, color. American Meteorological Society.

The Inconstant Air. 27 minutes, color. McGraw-Hill Text-Films, 1960. Planet Earth Series. Discusses weather and climate, with descriptions of atmospheric circulation, the role of the sun, and the collection of meteorological data. Time-lapse storm photography.

Solar Radiation I: Sun and Earth. 20 minutes, color. American Meteorological Society.

What Makes the Wind Blow? 16 minutes, color. American Geological Institute — Encyclopaedia Britannica Educational Corp., 1964. Step-by-step search for cause of typical on-shore breeze.

Other aids

Kalliroscopes are containers of crystal-filled liquid you can use to illustrate convection currents. Heat from your hand forms swirling patterns of light and shadow. They are available from Kalliroscope Corporation, 145 Main Street, Cambridge, Mass., 02142.

7. Wind, Weather, and Climate

Chapter Objectives

After completing this chapter, students should be able to:

1. Describe the life cycle of a frontal cyclone and the typical weather it produces.
2. Explain why large cyclones and anticyclones commonly occur together.
3. Relate local weather changes to the moving patterns of weather.
4. Identify at least three major climatic regions on a model continent and explain what physical processes are responsible for their location.
5. List three factors that may have caused the ice ages.

Teaching the Chapter

Students complete the Weather Watch begun in Chapter 3 as the opening activity in this chapter. Chapter 7 ties local weather changes such as the ones observed in the Weather Watch to the movement of large-scale weather systems. The physical causes of weather and climate were developed in Chapters 5 and 6. They are used now to explain how cyclones and anticyclones form and why there are recognizable climatic patterns on a typical continent. Investigation 7–10 challenges students to coordinate the information from recent chapters and deduce the climates of an imaginary continent.

Climatic change is presented as an unsolved problem that eventually may have a solution. Research into the causes of ice ages and the effects of man's activities on weather and climate are treated as part of this problem.

Suggested time required

It will take eight to ten days to complete the investigations and discuss the topics in this chapter.

Section Notes

7–1
Investigating the weather — Weather Watch

Advance preparation

This investigation summarizes students' observations of local weather changes during the weeks that the Weather Watch has been in progress. The weather maps and wall chart data for the time that readings were taken should be available.

Time requirements

Pre-lab	5–10 minutes
Lab	25–30 minutes
Post-lab	15 minutes

Special notes

It is important to select for analysis a week from the chart in which marked changes in the weather took place. An example of a good "weather week" can be found in Figure 3–1. If well-developed cyclones and anticyclones are moving over your locality from west to east, changes will be pronounced and relationships easier to identify. Changes probably will be more pronounced toward the end of the Weather Watch as the polar front migrates southward in winter.

Pre-lab discussion

Explain to the students that they will be performing a statistical investigation of a number of weather factors. An excellent way to analyze the Weather Watch data for the relationships suggested in the Text is to prepare a contingency table for each set of variables investigated. You could suggest that students follow the examples shown in the tables in Guide Figure 7–1 on the following page.

GUIDE FIGURE 7–1 Contingency tables for Weather Watch

A

Pressure Change During Day	Prevailing Wind Direction During Day: Northerly	Southerly
Rising	II	
Falling		IIII

Probability of northerly wind with rising pressure $\frac{2}{2+0} = \frac{2}{2} = 1.0$

Probability of northerly wind with falling pressure $\frac{0}{0+4} = \frac{0}{4} = 0.0$

Probability of southerly wind with rising pressure $\frac{0}{2+0} = \frac{0}{2} = 0.0$

Probability of southerly wind with falling pressure $\frac{4}{0+4} = \frac{4}{4} = 1.0$

B

Pressure Change During Day	Temperature Change During Day: Rising	Falling
Rising		II
Falling	IIII	I

Probability of rising temperature with rising pressure $\frac{0}{0+2} = \frac{0}{2} = 0.0$

Probability of rising temperature with falling pressure $\frac{4}{4+1} = \frac{4}{5} = 0.8$

Probability of falling temperature with rising pressure $\frac{2}{0+2} = \frac{2}{2} = 1.0$

Probability of falling temperature with falling pressure $\frac{1}{4+1} = \frac{1}{5} = 0.2$

C

Pressure Change During Day	Average Cloudiness During Day: Clear	Partly Cloudy	Cloudy
Rising	II		
Falling	I	II	II

Probability of clear sky with rising pressure $\frac{2}{2+0+0} = \frac{2}{2} = 1.0$

Probability of clear sky with falling pressure $\frac{1}{1+2+2} = \frac{1}{5} = 0.2$

Probability of partly cloudy with rising pressure $\frac{0}{2+0+0} = \frac{0}{2} = 0.0$

Probability of partly cloudy with falling pressure $\frac{2}{1+2+2} = \frac{2}{5} = 0.4$

Probability of cloudy sky with rising pressure $\frac{0}{2+0+0} = \frac{0}{2} = 0.0$

Probability of cloudy sky with falling pressure $\frac{2}{1+2+2} = \frac{2}{5} = 0.4$

D

Pressure Change During Day	Precipitation During Day: Yes	No
Rising		II
Falling	II	III

Probability of precipitation with rising pressure $\frac{0}{0+2} = \frac{0}{2} = 0.0$

Probability of precipitation with falling pressure $\frac{2}{2+3} = \frac{2}{5} = 0.4$

Probability of no precipitation with rising pressure $\frac{2}{0+2} = \frac{2}{2} = 1.0$

Probability of no precipitation with falling pressure $\frac{3}{2+3} = \frac{3}{5} = 0.6$

Notes on procedure

Have students construct the contingency tables and match the variables. You can explain that the data in the sample contingency tables is the same as that in Figure 3–1. Guide Figure 7–1A, for example, matches southerly and northerly winds with falling and rising pressure. Between September 1 and 2 in the sample Weather Watch the prevailing wind direction was southerly and the pressure fell. This means placing a tally mark in the box of Guide Figure 7–1A that matches southerly winds with falling pressure. Follow the same procedure for all the weather elements related by the four contingency tables. If the 24-hour change is zero, it is simpler to eliminate this observation than to set up another category.

Four of the seven observations in Guide Figure 7–1A were of southerly winds, and all of these occurred with falling pressure. Two were of northerly winds, both of them with rising pressure. The probability of southerly winds combined with falling pressure is thus 4 divided by $0 + 4$, or 1.0. The probability of northerly winds combined with falling pressure is 0 divided by $0 + 4$, or 0. (Significant results would require many more observations.) It is not necessary to have all of the students make the computations. It is more important for students to understand the relationships than to work out the mathematical probabilities.

Discuss the relationships (questions 1 through 4) when the students have filled out the four parts of Guide Figure 7–1. Then examine the weather maps posted on the board in chronological sequence, to see if the results can be explained in terms of the movement of weather systems across your locality.

Range of results

Since all groups use the same basic data, their results should be the same except for counting and arithmetic errors.

Post-lab discussion

The discussion should center around the contingency tables. Discuss the causes of these relationships and their relation to the weather systems shown on the daily weather maps. For most of the United States, the patterns of weather in the winter are determined by the activity of polar-front cyclones. You can add to class interest by relating the discussion to current weather conditions.

If the question of weather changes related to day and night comes up, point out that some of these daily variations have been eliminated by making observations at the same time every day.

Answers to questions

See if you can discover relations between the following weather elements:

1. Wind direction and changes in pressure. **Answer** In the Northern Hemisphere, the wind blows nearly parallel to the isobars, with high pressure to the right of its path. Southerly winds, therefore, should occur with falling pressure, as a low-pressure center approaches from the west. Northerly winds should occur after the low passes with the approach of a high-pressure center. However, since lows and highs may move in other directions, a southerly or northerly wind will not accompany every pressure change.
2. Change of temperature and changes in pressure. **Answer** Ordinarily, rising temperatures are associated with falling pressure and falling temperatures with rising pressure. However, land and water areas, latitude, precipitation, and cloudiness all influence air temperature. You should not expect a perfect relationship between pressure and temperature changes.
3. Cloudiness and changes in pressure. **Answer** Over much of the middle latitudes the moisture-bearing winds come primarily from southerly directions and the dry winds from northerly directions. Cloudiness is generally associated with falling pressure and clear skies with rising pressure. However, the direction of moisture sources is different in different regions, so the trends may be different or even reversed in some localities.
4. Precipitation and changes in pressure. **Answer** Over much of the middle latitudes, precipitation comes with southerly winds that are warm and moist. Most precipitation occurs

when air masses moving from the south rise over a warm front. The precipitation area is usually located in the forward half of the cyclone where pressure is falling as the center approaches. The drier, sinking air mass is usually located behind the cyclone where the pressure is rising. Again, this generality may not hold for all localities and weather conditions.

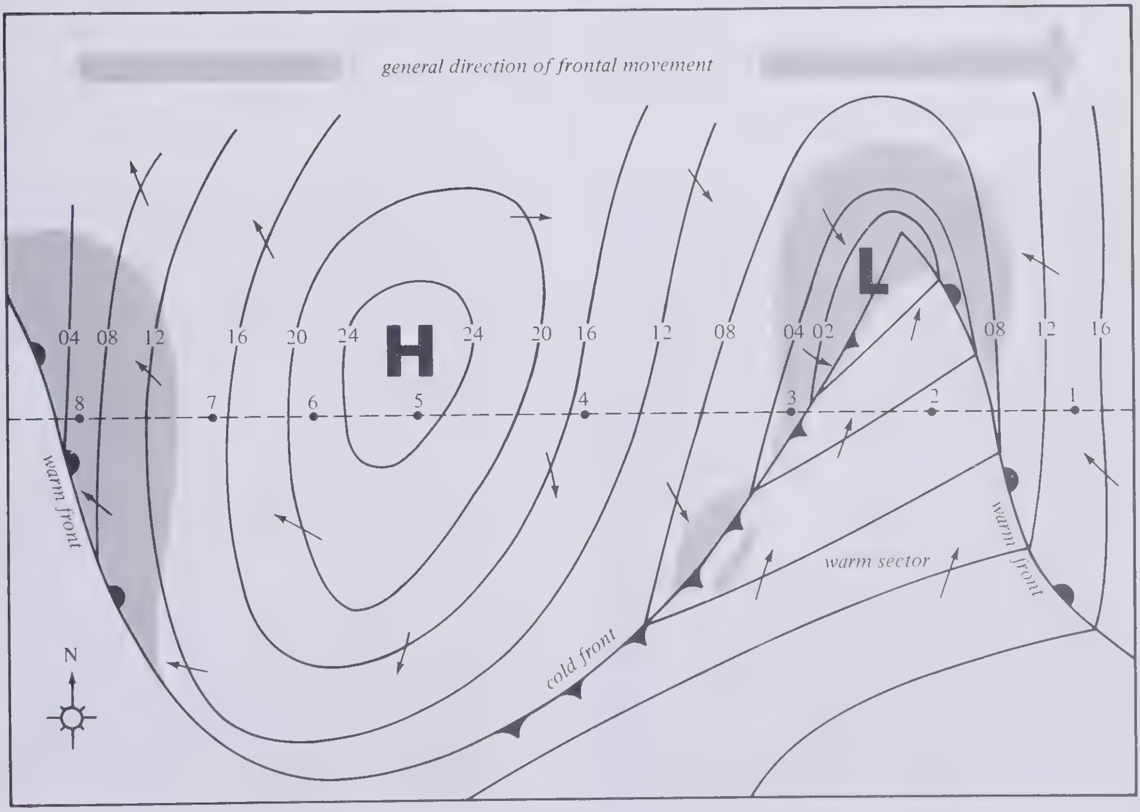
5. Explain how the local weather changes fit into the broad pattern of weather moving across the continent. **Answer** In general, southerly winds over the middle latitudes are moisture-bearing winds. Precipitation usually occurs on the forward side of a moving low-pressure region. As the low approaches a locality, these changes occur: the pressure falls, the wind becomes southerly, the temperature rises, the warm air mass rises over the warm front, and precipitation may occur. When the low has passed, the pressure rises. The wind shifts to northerly, the temperature falls, and the weather clears. Along the west coast of the United States, where the moisture-bearing winds may come from the west or northwest, clouds and precipitation may come mainly with northerly winds and rising pressure.

The observations shown in the sample Weather Watch are indicated along the dashed line through the middle of Guide Figure 7–2. This shows the movement of a cyclone and anticyclone across a local station on eight successive days. While it may not be possible to select such an ideal situation from your wall chart and weather maps for your locality, students should understand this basic model and be able to compare their weather to it.

Suggested additional investigations

Several teachers have reported interesting results when students construct scattergrams using possible relationships between various weather data. Students plot the data for each day on the scattergram, using any two factors that have been recorded in the Weather Watch. This should be done for at least several weeks. In addition to weather data, students have used other data such as the number of students absent from school,

Guide Figure 7–2
Numbers mark the position of a frontal system on eight successive days.



depth of water in nearby ponds or wells, number of emergency runs made by local fire departments, and other factors which may or may not be affected by the local weather. Sample scattergrams and apparent relationships are shown in Guide Figure 7–3. Of course, these results may be different in other locations at other times.

7–2
Cyclones and anticyclones

An excellent account of cyclone and anticyclone formation and development is in Sutcliffe's *Weather and Climate* (see Supplementary Materials).

Throughout this section you will find the U.S. Daily Weather Map a useful aid. Be sure to point out that the cyclone model developed in the Text is idealized, and that many variations of it are evident on the Weather Map.

7–3
Warm and cold fronts

Action As students carefully remove the separating wall from the tank, the denser salt water flows along the bottom of the tank toward the opposite side and forces the fresh water upward. The salt water corresponds to a cold air mass in the atmosphere, and the fresh water to a warm air mass.

The interface between the dense and less dense water becomes horizontal because gravity, the only appreciable force involved, is perpendicular to the water's surface. In the atmosphere, however, the interface or frontal surface between cold and warm air masses ordinarily slopes. Students may ask why this is so. On the earth, the combined influence of the pressure force, the Coriolis effect, and gravity is such that fronts between two air masses of different density need not be horizontal to reach equilibrium.

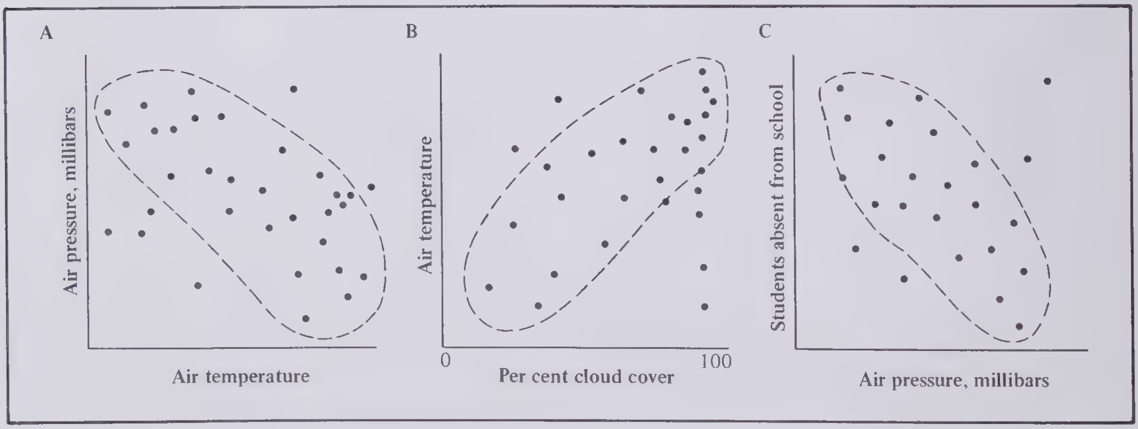
Treating the developing cyclone as an example of a special kind of convection will make the point that all air motions are essentially convective, involving the transformation of potential to kinetic energy.

Demonstration To help students visualize the structure and movement of the polar-front cyclone, you can draw, or have the students draw, a polar front with cold and warm fronts identified on the clear plastic hemisphere of the Globe Kit, as in Guide Figure 7–4.

Place the plastic hemisphere over the Northern Hemisphere of the globe and rotate it slowly from west to east. It commonly takes about three to five days for a cyclone to pass across the United States or Canada from the Pacific to the Atlantic Coast.

Note that the high pressure in the polar region is permanent, as are the highs over the Pacific and Atlantic Oceans at about 30 degrees latitude. (See Section 6–8.) However, the low at the polar front moves like a wave, with a high moving in behind it as the storm (low) moves from west to east. The polar front is most active between about 40 to 60 degrees. It is alternately under the influence of low pressure (convergence) and high pressure (divergence). The low

Guide Figure 7–3
Sample student scattergrams for Investigation 7–1 showing typical apparent relationships recorded during the Weather Watch.



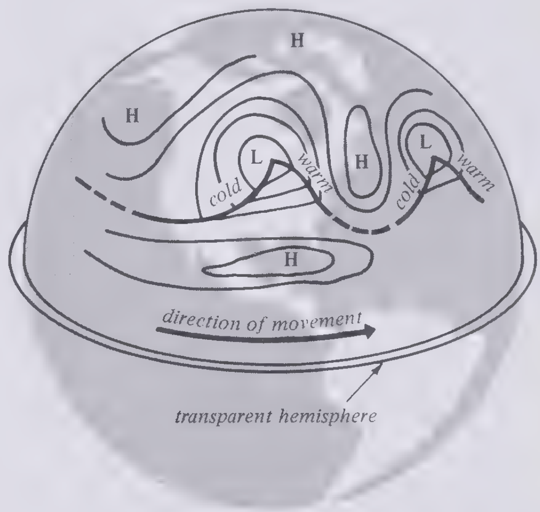
and the associated warm and cold fronts bring the clouds and precipitation.

When the students identify this relationship, ask if they can use the plastic hemisphere for the Southern Hemisphere. They find that the cyclone must be redrawn as a mirror image of that in the Northern Hemisphere. Polar-front cyclones in the Southern Hemisphere also move from west to east, driven by the westerlies and the jet stream.

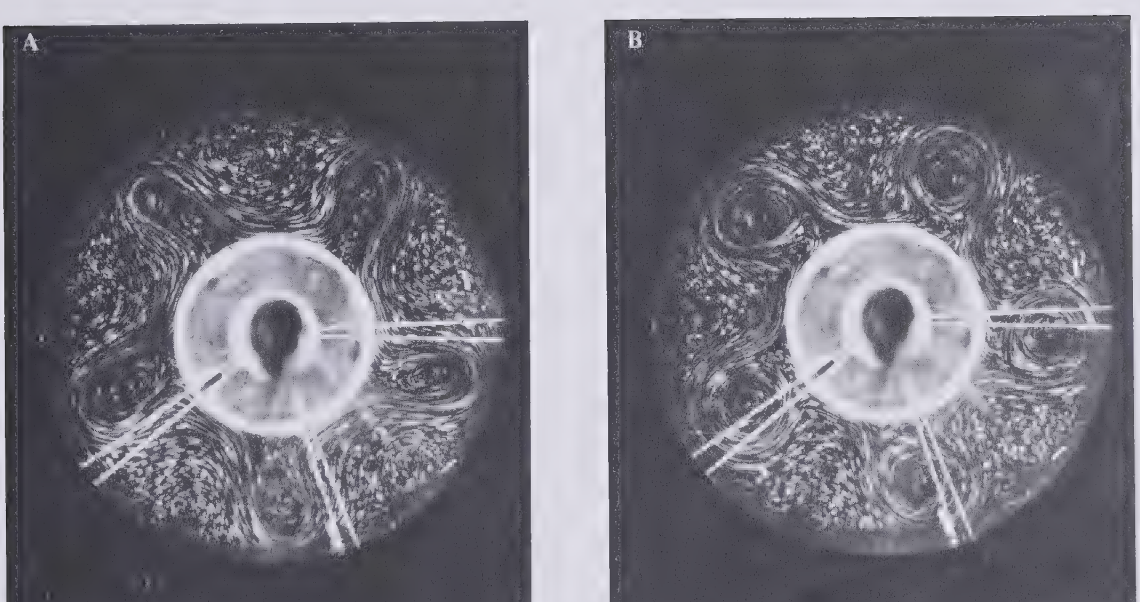
The polar front and its disturbances greatly complicate the atmosphere's motion patterns. Experiments with rotating pans of water, heated at the rim and cooled at the center, illustrate this instability of the general circulation. Information on the design of rotating-fluid experiments suitable for high school demonstration can be obtained from the Department of Geophysical Sciences, University of Chicago, Illinois.

Photographs of such an experiment are shown in Guide Figure 7–5. Streaks of powder floating

GUIDE FIGURE 7–4
Using the Globe Kit to show the motion of frontal systems.



GUIDE FIGURE 7–5
A laboratory model illustrating circulation patterns in air near the earth's surface. Rotating pans of water were heated at the rim and cooled at the center to make the patterns.



in the water show its motion during a time exposure. A narrow current meanders around the center of the pan in the direction of rotation. This current is called a jet stream; it duplicates the flow of the atmosphere's jet stream at a height of 10 to 12 kilometers. There are also smaller eddies, some of which move counterclockwise around their centers. These resemble the anticyclones of the earth's atmosphere. After one rotation of the pan, representing a day, the pattern of motion changes noticeably.

7–4
Air motions and weather

Review Section 6–8 to point out how converging air currents near the earth's surface produce rising motion. Refer to the cellular circulation of Figure 6–15 and ask the students to identify the belts of heavy and light rainfall. The belts of heavy precipitation reflect the upward motions of moist air including those caused by cyclones at the polar front.

Not all precipitation occurs along the polar front. Thunderstorms that develop within air masses far from frontal zones also cause much precipitation. These local storms are caused by small-scale convection cells.

7–5
Thunderstorms
7–6
Tornadoes and hurricanes

Students are usually interested in thunderstorms, tornadoes, and hurricanes. The basic information in the Text may be supplemented by reference to popular books which appear each year or to public information brochures from the National Oceanic and Atmospheric Administration (NOAA). The Government Printing Office lists publications about weather and climate, full of statistics on storms. Sections on forecasting and warning procedures tie in especially well to the topics in this chapter.

As a class project you might assign students to compile information on the storms that affect your locality. Reports might be made on storm frequency, the large-scale weather patterns that favor storms, the effects of storms on buildings, and safety procedures.

For a view of the importance of severe storms, ask a student to report to the class on the loss of life attributed to tropical cyclones in Bangla Desh (East Pakistan) during the past 20 years. Information can be found in almanacs and encyclopedias.

Answers to thought and discussion

1. How does a cyclone transfer heat: upward or downward? Toward the pole, or toward the equator? **Answer** Since the temperature is warmer at the earth's surface than in the atmosphere above it, a cyclone transfers heat upward. Since the poleward-moving winds of the cyclone are warmer than the equatorward-moving winds, a cyclone transfers heat poleward. If the students use the U.S. Daily Weather Map to determine the direction of heat transfer in a cyclone, they will note the warm rising air moving poleward on the east side of the cyclone and the cooler air moving equatorward on the west side.
2. When air converges, it develops cyclonic rotation. When it diverges, it develops anticyclonic rotation. Would this happen if the earth were not rotating? **Answer** If the earth were not rotating, diverging and converging currents could still lead to rotation, but the direction of the rotation would not necessarily be consistent. Refer back to the Action in Section 7–3. The direction of rotation is determined by the direction of rotation of the earth.
3. In Chapter 4, you learned that the earth rotates in space around every point on its surface except at the equator. Tropical cyclones do not develop right at the equator. Are these facts related? **Answer** Yes. Tropical cyclones do not develop right at the equator, apparently because the direction of spin is opposite on opposite sides of the equator. At the equator the horizontal force of the Coriolis effect is zero.

7–7
The general circulation and patterns of climate

Review briefly the effect of the distribution of solar radiation on the world's temperature pattern (Chapter 6). Like the temperature pattern, the pattern of rainfall is primarily latitudinal, but land, water, and topography all introduce variations. What causes your area to vary from the average pattern for its latitude?

Review the concepts of evaporation, atmospheric transport, and precipitation of water from Chapter 5, and use ideas on wind and pressure belts from Chapter 6 to illustrate how energy and moisture are related.

Note in Figure 7–13 that the spacing between 10–degree intervals of latitude decreases toward the pole. You might show students on a globe that the spacing is drawn in proportion to the area on the earth at each latitude. This gives a better picture of the amounts of water involved than a linear scale would. You also can relate Figure 7–13 to ocean salinity. Low salinity occurs in surplus zones, high salinity occurs in deficit zones.

One way you can show the effects of the seasonal shift of climatic belts is by having the students construct temperature and precipitation graphs for typical weather stations at various latitudes. Data to use for this exercise can be found in most elementary physical geography textbooks.

7–8
Geography influences climate.

Students should have little trouble understanding the influence of land and water on climate zones if they have done Investigation 6–5 and understand simple convective circulation.

Action The values students derive should be approximately those found in Guide Figure 7–6.

Eastern Asia shows the greatest annual range because it is the largest continent. Both deserts and humid areas deep in the interior have bitter cold winters and comparatively warm summers for their latitudes. The oceans show the smallest range. Land heats and cools faster than water because water has a higher specific heat, is transparent, and is mobile. Weather in island and coastal locations is moderated by the nearby ocean climate. This is evident in the annual temperature range map in Figure 7–16.

Temperature-range variations along 60 degrees south latitude are very slight at all longitudes because there are no continents to alter the energy pattern.

7–9
Mountains further modify the pattern.

While the distribution of continents and oceans is the most profound modifier of the basic latitudinal pattern of climate, terrain features, especially mountains, have a marked influence on

GUIDE FIGURE 7–6
Temperature Chart for the Action in Section 7–8.

TEMPERATURE IN °C	GULF OF ALASKA	CENTRAL CANADA	NORTH ATLANTIC	EASTERN ASIA
July	10(50)	10(50)	15(59)	15(59)
January	−10(14)	−30(−22)	5(41)	−35(−31)
Temperature Difference	20(36)	40(72)	10(18)	50(90)

Values in ( ) are in °F.

local and even regional patterns. Using Guide Figure 7–7 as a model, sketch on the chalkboard the diagram of an air mass crossing a mountain. Ask the students to describe what happens at each position in the diagram. As each position is analyzed, you can plot the points shown in the graph. What has happened to the temperature of the air mass? Where did the added heat come from? Where in the United States does this effect seem to have affected the climate?

7–10
Investigating the climates of an imaginary continent

Advance preparation

Use the transparency master at the end of this Guide to make a duplicating master. Make a copy of the imaginary continent map for each student.

Time requirements

Pre-lab	5 minutes
Lab	25 minutes
Post-lab	20 minutes

Pre-lab discussion

A brief review of the major climatic controls should lead up to this investigation. This could be done on the day before the investigation. The most important controls are: 1) the distribution of solar radiation, 2) the general wind pattern, 3) the pattern of converging and diverging air masses, 4) the patterns of upward and downward air motions, 5) the distribution of land, water, and ocean currents, and 6) the arrangement of mountain ranges with respect to the prevailing winds.

Tell the students that this investigation will provide an opportunity to tie together the numerous factors that control the earth's climate.

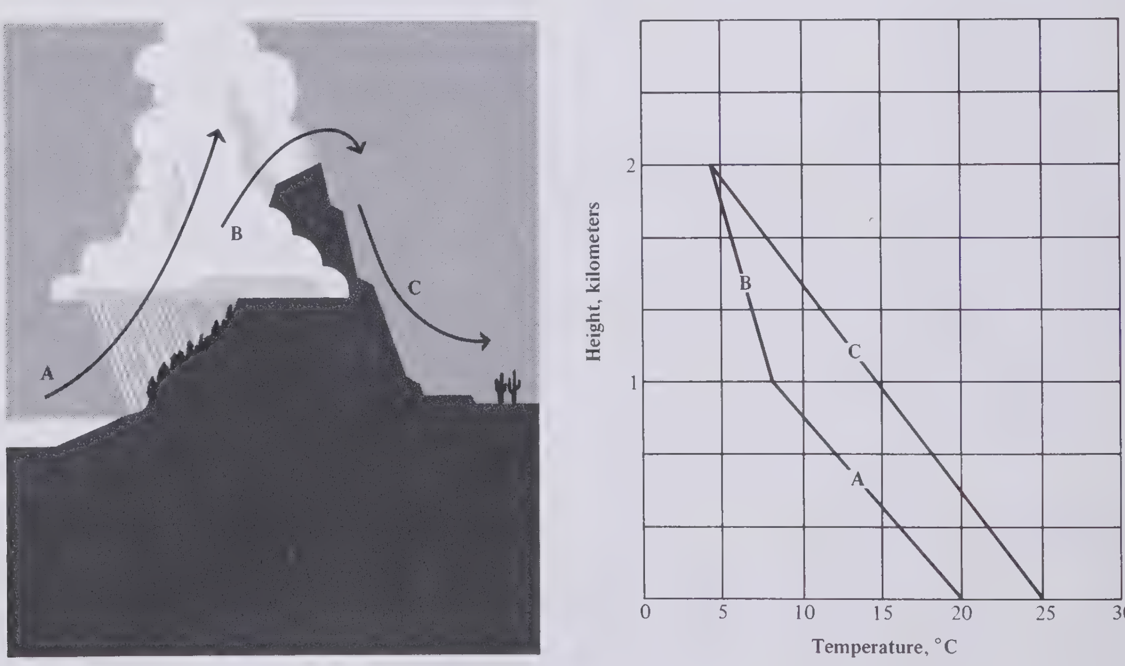
Notes on procedure

Distribute the maps of the imaginary continents. Some students may ask if this is a continent on the earth and if it is surrounded by ocean. The answer is yes to both questions.

To locate the major latitudinal zones of converging and diverging masses, students will have to sketch the prevailing winds. (Figure 6–16 can serve as a pattern.)

Students may refer to Figure 7–13 to determine latitudinal patterns of moisture and dryness. The most important boundary line is the one separating wet regions from dry ones. (See Guide Figure 7–8.) Once this boundary has been marked for both the Northern and Southern Hemispheres, students can subdivide these areas into temperature regions.

Guide Figure 7–7
An air mass changes temperature as it rises over a coastal mountain range.



Range of results

Student results will range widely, but the location of wet and dry zones should resemble that in Guide Figure 7–8. Those who have followed the Text carefully may include the subtropical desert regions characteristic of the west coasts of continents. The latitudinal distribution of temperature should be clear to the students, but the interactions between moisture and temperature leading to the more complex classification shown in Guide Figure 7–9 will not be obvious to most students. They will simply classify moisture and temperature zones independently.

Post-lab discussion

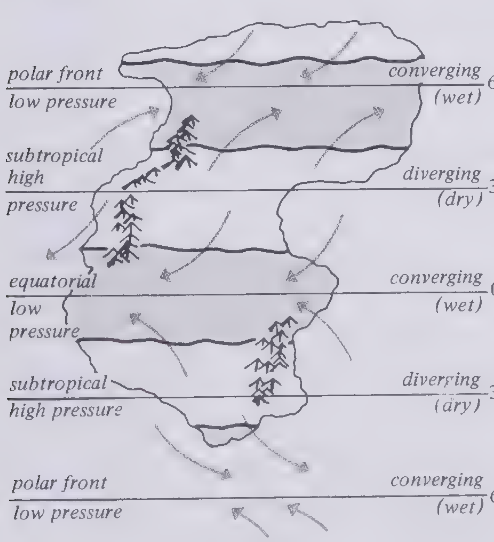
Most important points will be covered in the answers to questions.

Answers to questions

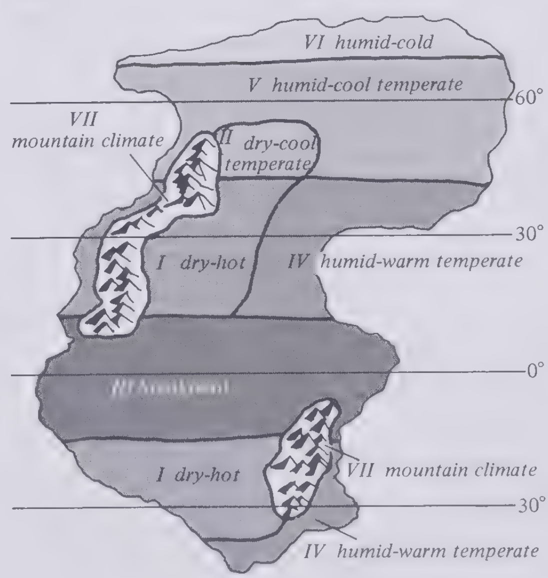
1. Locate the major latitudinal zones of converging and diverging air masses. In each case, indicate which are the wet zones and which are the dry zones. **Answer** See Guide Figure 7–8.
2. Sketch in the boundaries between climatic regions on the imaginary continent. Start by outlining the dry regions. Label all regions by their temperature and moisture conditions, such as hot, warm, or cold and humid or dry. **Answer** Guide Figure 7–8 shows the first step. Guide Figure 7–9 is the typical climatic classification for the imaginary continent. Although the discussion in the Text is fairly explicit, students could not be expected to reproduce all the details of Guide Figure 7–9. A few students may be able to identify the four humid and the two dry regions. Mountain areas may also be recognized as separate climatic regions.
3. Explain the temperature and moisture conditions in terms of latitude, land-water differences, mountain ranges, air motions, and the differences between evāporation and precipitation. **Answer** Roman numerals are keyed to regions I through VII in Guide Figure 7–9.

   I. Dry, because of descending air of the subtropical high and cool ocean currents that stabilize air masses. Hot or warm all year because of nearness to equator and sun always fairly high.
   II. Dry because of rain shadow and/or distance from the sea. Temperate because in middle latitudes.
   III. Humid because of rising and cooling air where trade winds meet (convergence). Hot because sun nearly overhead all year.
   IV. Humid because of moist, onshore monsoons in summer. Hot or warm summers as sun approaches overhead. Winters cool, especially in poleward portions. On the basis of an annual mean, this might

Guide Figure 7–8
Imaginary continent showing wet and dry zones.



Guide Figure 7–9
Imaginary continent showing climate regions.



be called a warm temperate climate, as it occupies the equatorward portion of the middle latitudes, but the students may recognize the seasonal variation.

V. Humid because of convergence at polar front, with warm air rising over cold air and condensing. From the basis of an annual mean, this region might be called cool temperate, since it is in the poleward portion of the middle latitudes. However, the students may recognize warm summers and cold winters.

VI. Humid because evaporation so low, not because of much precipitation. Cold or cool all year because of low sun angle.

VII. Variable mountain climates with generally greater precipitation and cooler temperatures than surrounding regions. Lower temperatures and higher precipitation make most mountain areas humid.

7–11
The changing atmosphere and climates
7–12
Causes of ice ages

Climatic changes represent an appealing topic for newswriters. Since the topic appears often in the popular press, students probably will raise many questions about the prospects for changes in the earth's climate.

The topic of the causes of ice ages is an unresolved problem that poses an enormous challenge to the scientist. There is perhaps no other problem where possible explanations go so far into so many of the various disciplines of earth science. It is quite possible that several different factors — astronomical, geological, atmospheric, and oceanic — have to occur in unison to produce an ice age. It is even possible that an ice age could be brought about without any external changes. That is, an ice age could be a consequence of the normal variations in the atmosphere-ocean system. Scientists still do not know.

7–13
Urban influences on climate

Air pollution will be a popular topic among students. Many students will be more concerned about the changes in the quality of the air we breathe than about climatic changes, although the two could be related. *The Pollution Game,* listed in Supplementary Materials, is a board game students can play. It will help your class realize the difficulties faced in pollution control.

You can build a class discussion on air pollution around Guide Figure 7–10. Either make transparencies of the first two graphs that you can overlay to produce the complete graph, or sketch the graphs on a blackboard using two colors of chalk.

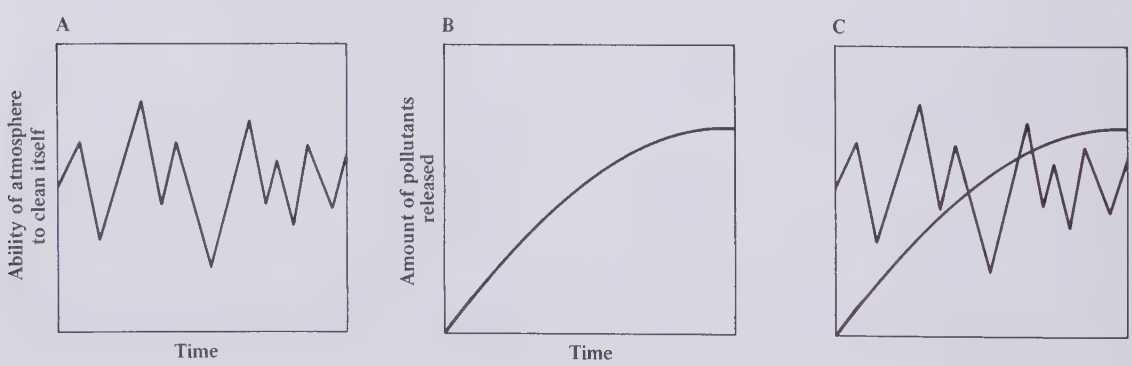
Guide Figure 7–10A shows that although on the average the capacity of the atmosphere to remove or dilute pollutants remains constant, it varies from day to day depending on air motion and precipitation.

If students recorded visibility in their Weather Watch, they will have an idea of the scale of variation in this graph. Questions you might ask to guide discussion include: How would pollution particles be removed by precipitation? Under what circumstances would the particles stay in the air and increase pollution? How do stable and unstable air masses affect the concentration of pollutants in the air?

Next introduce Guide Figure 7–10B, which shows a situation where more and more pol-

Guide Figure 7–10

Graph C shows what happens to air quality when pollutants are released (Graph B) into an atmosphere that can clean itself at only a certain rate (Graph A).



lutants are put into the atmosphere. Then superimpose the two graphs and point out that where the pollution curve is above the air cleaning line, the pollution level is very high. What happens to the length of successive air pollution episodes? What happens to their frequency? Eventually the graph reaches a point where the atmosphere cannot cleanse itself even under the most favorable conditions.

Answers to thought and discussion

1. There is very little water vapor in the stratosphere. If water vapor were put there by some means, would it tend to remain for a long time? **Answer** Yes. For water vapor to condense out of the atmosphere as rain, the moisture-bearing air must be lifted and cooled. The stratosphere, however, is very stable. There are no upward currents of air, and the temperature is constant or increases with altitude.
2. Dust in the stratosphere helps cool the earth's surface, while dust near the earth's surface may have an opposite effect. Can you suggest why the effects might be different? **Answer** Dust in the stratosphere stops sunlight from reaching the earth's surface. The dust reflects some of the energy back into space. It also absorbs some of the energy. Dust near the earth's surface does the same thing, but it also may act like a blanket, absorbing some of the heat radiating from the earth's surface that normally is lost in space. The dust layer then reradiates the energy back to earth. It may send more energy back to earth than it stops from getting through.

Discussion of unsolved problems

Students probably will mention that some of the factors listed in the Text are likely to occur very slowly, or very far in the future. How would your class arrange the list of causes of changing climate to put the fastest-acting factor on top and the slowest factor at the bottom? If a factor is unfamiliar to the students, they can either guess at its position or leave it out. No one knows for sure, of course, but one scientist ranked the factors in the same order they are listed.

How fast could the climate change? The first five factors on the list could have an effect on climate in ten years or so. The next four might take a few hundred, or a few hundred thousand years. The estimates of how long it would take the rest of the factors range upward from one million years.

Answers to questions and problems

A

1. Describe the stages in the development of a polar-front cyclone. Why is a cyclone usually accompanied by an anticyclone? **Answer** A cyclone appears first as a wave or ripple on the polar front. A cyclone disturbance forms as the forward portion of the front is overtaken by the rear portion of the front. The warm sector between the two fronts is gradually narrowed as the cold front overtakes the warm front and the cyclone becomes occluded. Figure 7–3 shows how cyclones and anticyclones develop under a wave in the westerlies. This illustrates why the symmetry of the wave causes lows and highs to develop at the same time.
2. Tropical cyclones usually lose force when they move over a large land area. Why? **Answer** The energy used in evaporating sea water comes from the tropical or subtropical ocean. This energy is carried upward as latent heat, then released when the water vapor condenses. (See Figure 7–11.) Over land areas this energy is not available in the large quantities needed to maintain a tropical cyclone.
3. Small whirlwinds called "dust devils" rotate either clockwise or counterclockwise, although tornadoes rotate cyclonically. Can you suggest why? **Answer** Tornadoes develop in large clouds that are already rotating in a counterclockwise direction (Northern Hemisphere) because of the Coriolis force. The motions of the mother cloud of the tornado are on a scale large enough for the earth's rotation to be effective. Dust devils are the result of small-scale convection. Like the bathtub vortex,

their direction of spin may be cyclonic or anticyclonic because the air may be initially rotating in either direction.

4. Where are the wet and dry belts in the basic climatic pattern of the earth and how are they produced? **Answer** The wet belts in the basic rainfall pattern of the earth are produced by rising motion at the polar front and in the Intertropical Convergence Zone. The dry belts are produced by the sinking air in the subtropical high-pressure belt and by air in the polar regions that cools by radiation and sinks to the earth's surface.

B

1. The polar front has been far north of its usual position for the past month. Was the rainfall during this period along the usual position of the polar front greater or less than normal? **Answer** Under these conditions, rainfall would ordinarily be less than normal along the usual position of the polar front. However, an influx of moisture could result in convective clouds and rainfall.
2. A rapidly occluding cyclone has just passed over your area. Would you expect the forward movement of the storm to speed up or slow down during the next 24 hours? **Answer** As a cyclone occludes, its eddylike circulation extends well into the troposphere, and its forward movement tends to decrease. The loss of air ahead of the cyclone (divergence) that produces its forward motion is part of the developing stage of the cyclone. Development and forward movement are thus closely related, and a cyclone that is dying loses this movement and slows down.
3. At the advanced stage of a glacial period, the average temperature of the earth may be lowered by about 9°F and the ocean temperatures would also be colder. How would this affect the amount of evaporation? **Answer** The lowering of the temperature would reduce the evaporation. Less energy would be available for evaporation from the ocean surface, and the colder air could not contain as much water vapor.

C

1. Explain how periodic changes in the earth's position in its orbit could cause the polar ice caps to spread toward the equator. **Answer** The changes in the earth's position in its orbit can cause the seasonal changes of solar radiation to be smaller. This results in milder winters and cooler summers at high latitudes. The milder winters produce more storms and more snow at higher latitudes, because the polar front is displaced toward the poles. The cooler summers result in less melting of the snow cover laid down in the winter. In this way the polar ice caps could spread toward the equator until the cycle changes and warmer summers occur.
2. Why do cyclones rotate in opposite directions in the Northern and Southern Hemispheres? **Answer** The Coriolis force acts in opposite directions in the two hemispheres. It deflects the moving air to the right of its path in the Northern Hemisphere and to the left of its path in the Southern Hemisphere.
3. How do mountain ranges affect the climate where the wind blows moist air against them? **Answer** Air is forced upward, and the water vapor in the air cools. This produces more cloudiness and precipitation on the side of the mountain range the wind is blowing against. Cloudiness and precipitation may spread a short distance on the downward side, but the descending air warms. This leads to higher relative humidity, so the climate is dry on the downwind side of the mountain range.
4. Why are the interiors of continents likely to be dry? **Answer** The interiors of large continents are far from sources of moisture. Storms may lose all their moisture before they arrive at the interior of the continent, particularly if the prevailing winds blow over mountain ranges near the coast.
5. Very little precipitation occurs in the polar regions, yet these regions are not deserts in the true sense of the word. Why? **Answer** Although little precipitation may occur in the polar regions, the evaporation is small because of the low temperature. The climate may therefore be relatively humid, and the soil moist.

Supplementary Materials

Reference books

Riehl, Herbert. *Introduction to the Atmosphere.* McGraw-Hill Book Company, New York, 1972. For the nonspecialist student.

Strahler, Arthur N. *The Earth Sciences,* 2nd ed. Harper & Row, New York, 1971.

Sutcliffe, Reginald C. *Weather and Climate.* World Publishing Co., New York, 1969. (Paperback)

Ludlum, David M. *Weather Record Book.* Weatherwise, Inc., Princeton, N.J., 1971. Outstanding weather events 1871–1970.

Films

The Inconstant Air. 27 minutes, color. McGraw-Hill Text-Films, 1960. Planet Earth Series. Discusses weather and climate, with descriptions of atmospheric circulation, the role of the sun, and the collection of meteorological data. Time-lapse storm photography.

Above the Horizon. 21 minutes, color. American Meteorological Society. Birdseye view of the field of meteorology.

Other aids

The Pollution Game, developed by Frederick Rasmussen of the Educational Research Council of America. Houghton Mifflin Company.

8. Waters of the Land

Chapter Objectives

After completing this chapter, students should be able to:

1. Describe how water infiltrates the ground and becomes capillary and gravity water.
2. Show how runoff depends on the form and intensity of precipitation and the storage conditions beneath the surface.
3. Explain why evaporation and transpiration depend on both the water and the energy available.
4. Describe in general terms how flood forecasts are made.
5. Explain how organic wastes affect the life cycle of lakes and rivers.

Teaching the Chapter

The preceding chapters of Unit II deal with the general circulation of water in the ocean and the atmosphere. In this chapter students investigate what happens to water after it reaches the land. Students investigate the importance of soil particle size to porosity, water retention, and permeability. Another investigation challenges students to predict from rainfall and streamflow records the height and arrival time of a flood. To do this students must apply their understanding of infiltration, runoff, and rainfall intensity.

Water is a common substance, and the major ideas of the water cycle on land can be illustrated readily by the students' experiences and observations. Simple demonstrations also are used to illustrate topics in the chapter. Because water has an apparently universal appeal for human beings — apart from satisfying physical needs — you should have no difficulty in stimulating interest and questions among students.

One of the most notable features of the study of water on land is that so much useful knowledge can be gained simply by measuring how much water there is and finding out where it is going. Predictions of some floods can be accurate because they are based on a simple accounting method: balancing income, storage, and outgo of water. This chapter discusses the physical processes that control the flow of water over, into, and under the earth's surface.

Suggested time required

It should take five to eight days to discuss the topics and complete the investigations in this chapter.

Section Notes

8–1
Where does fresh water come from?

Moisture other than rain is an important source of fresh water in some parts of the world. Discussing dew as a source of drinking water and the amount of moisture received from fogs will interest many students. You may wish to have several students give a class report on the means by which precipitation is collected throughout the world. Dew, frost, and fog, while not generally termed precipitation, may fall into this category if collected as sources of water.

Ask students to collect information about water problems in your local area. Students can bring in newspaper and magazine articles on the various problems involved in the collection, distribution, and purification of water throughout the United States.

Students may be interested in accounting for rainfall extremes and relating these to weather and climate (Figure 8–2).

8–2
How fresh water is stored

Infiltration, the entrance of water into the soil, may be discussed to relate this section to the following investigation and to Section 8–4.

The current public interest in ecology has led to numerous articles on difficulties caused by large dams and reservoirs. You might refer the students to articles on the Aswan Dam and Lake Nasser, where infiltration and evaporation have produced tremendous water losses. In tropical or subtropical regions, the water lost from reservoirs through transpiration (covered in Section 8–6) by the water hyacinth has been an enormous problem.

Action Students will probably find that the local water supply has several sources. You could expand the activity by assigning students to find a city whose water supply is a glacier, an underground source, or a lake. Or students could report to the class on cities whose water supply is unusually distant.

8–3
Investigating the movement of water in earth

Advance preparation

Check for leaking plastic columns where the caps attach. Have spares available.

Time requirements

Pre-lab	5 minutes
Lab	30–40 minutes
Post-lab	15–20 minutes

Materials

The following materials are needed for each group of two students:

- Plastic Column Kit or:
  - Plastic cylinder, 80 cm × 35 mm
  - Cap with drain hose
  - Hose clamp or hose cock
  - Cap screen to hold back beads
- Beads from Teacher's Kit, (approx. 4 mm, 6 mm, 8 mm), 500 ml of each per class
- Ring stand and clamp
- Beakers, 600 ml, 2
- Graduated cylinder, 100 ml
- Paper towels
- Meter stick
- Denatured alcohol, 2.5 l (optional)
- Fine dry sand, 200 ml
- Coarse dry sand, 200 ml
- Cloth, 10 cm diameter
- Rubber band
- Graph paper
- Liquid detergent

Special notes

The beads may float. To avoid this, have students add a drop of detergent to the water.

Students may cover the beads with water and then only measure the water drained off. This does not represent porosity.

If beads are not dry, or if air bubbles form when students begin the procedure, errors will occur in porosity and water retention measurements.

Pre-lab discussion

You might open the discussion by asking what happens when water enters the soil. How do the sizes of the beads compare to the sizes of particles in soil?

Notes on procedure

To reduce the number of beads required, use five columns of each size bead and have the students rotate in their use. In a class of 30 students, this uses 500 milliliters of each size bead three times per period rather than 1500 milliliters once.

To avoid errors in measuring porosity and water retention, dry beads between each use. One simple way to do this is to pour the beads from the column into an open, flat container and dry them with a paper towel. The beads will dry faster if the students pour denatured alcohol through the column of beads before drying them. The plastic column and drain should also be dried. You can use a meter stick to push a paper towel through the column.

To measure porosity students should put 100 milliliters of water in the graduated cylinder and then pour enough of the water into the column to just cover the beads. The difference between 100 milliliters and the amount of water left in the graduated cylinder is equal to the amount of air space between the beads.

Water retained (capillary water) can be measured by draining the column back into the graduated cylinder. The difference between 100

milliliters and the amount now in the graduated cylinder is the water retained.

The chief problem in measuring permeability is deciding when to stop timing the flow of water through the beads. Probably the best time to stop is when the solid stream of water from the drain tube changes to a trickle. If students time as long as water is dripping from the drain tube, ask them if this dripping represents water flowing through the beads. The dripping represents water that is sticking to the sides of the drain tube. Since the measurement errors occur when starting and stopping the timer, results can be improved by using more water. That is, the longer the flow time, the less significant a half-second error is.

The capillarity portion of the investigation requires two columns, so two groups will need to work together. The end of the column should be lowered far enough into the water to remain immersed when the water rises in the column. However, the end should not be so deeply immersed that water is forced up into the column. Students may look on this as a race between coarse sand and fine sand. Their experience with permeability will probably lead them to expect the coarse sand to win.

Range of results

Students' graphs should look something like the ones in Guide Figure 8–1. If the students extend their curves beyond the measured points, ask them how sure they are that this is valid.

The rate at which the water rises through the sand depends on the size of the sand grains. Fine sand has a faster rate of water rise. In any event, the water will start rising quickly, slow down, and will eventually stop rising completely.

Post-lab discussion

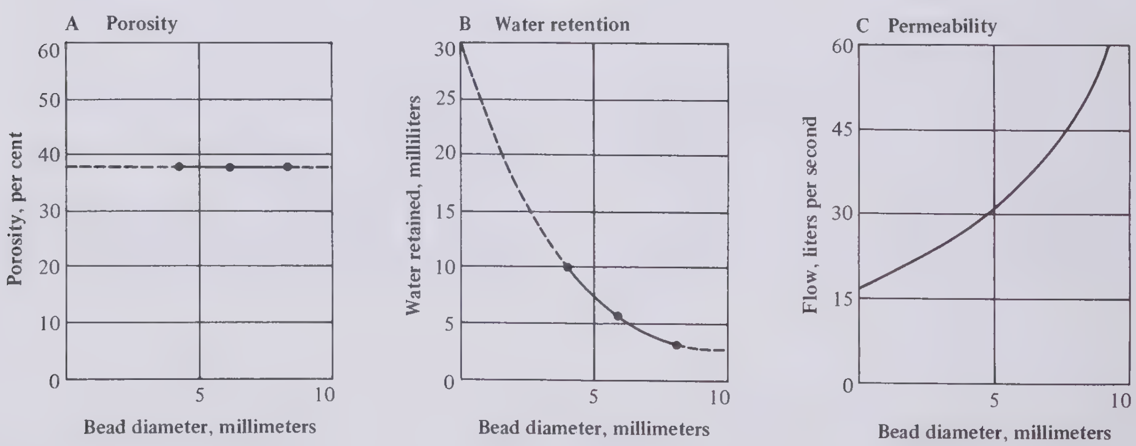
To start the discussion, ask students to define porosity, permeability, and capillarity. Compare the model used in the investigation with the natural processes represented. (See Section 8–4.) Ask if there is any relationship between the results of the capillarity portion and the amount of water retained by the beads in the first part of the investigation.

To sum up the investigation, you might ask why a stream or lake can hold water if its bottom is porous. After some thought, they should answer that while water does drain out, at some point drainage stops. Then ask why the drainage stops and why the water is held by soil and rock that are saturated with water. To answer this question, students must use the concepts of porosity, permeability, and capillarity.

Answers to questions

1. Find the volume of water necessary to *just* cover the upper surface of the particles. What per cent is it of the total volume (100 ml) occupied by the particles? **Answer** Graph A, Guide Figure 8–1, shows an idealized result. Actual student graphs usually will show some small variations. An average of class results should resemble Graph A.
2. Make a graph to see if the diameter of the particles seems to affect porosity. Explain your results. **Answer** The water added is equal in volume to the space between the grains. With small grains there are many small pores. With large grains there are fewer but larger pores. Thus, the ratio of pore space to the combined volume of grains remains the same, and porosity stays constant. The graph of

Guide Figure 8–1
Typical student graphs for Investigation 8–3.



porosity against particle diameter should look something like Guide Figure 8–1A.

3. Make a graph to see if the grain size seems to affect the amount of water retained in the column after draining. **Answer** The graph should look like Guide Figure 8–1B. From the graph the students can conclude that finer grains retain more water. This is because smaller grains provide more surface area and more points of contact between grains where water can adhere. Students should see that, as a consequence of this, not all ground water can drain away. Some capillary water stays on the surface of the particles and can be removed only by evaporation.
4. Make a graph to see if the size of the particles affects the rate water flowed through them (300 ml ÷ time). **Answer** The graph should look like Guide Figure 8–1C. It is easier for water to run through large pores. Friction at the grain surfaces slows the water down. Away from the surfaces the water flows more freely. As particle size — and thus pore size — increases, a greater portion of the water flows freely through the center of the pores. As pore size decreases, more of the water flows near the particles and is slowed down.
5. What do you think accounts for movement of water upward in the tube? **Answer** The students may have encountered capillary forces before. Capillary lift in a tube of small diameter is caused by the combined forces of surface tension and molecular attraction between the liquid and the wall of the tube. The students may think of the soil pores as small capillary tubes. (It is interesting to point out that the liquid must wet the tube walls for capillary rise to occur. Since mercury does not wet glass, mercury *sinks* inside a small tube dipped into a dish of mercury. The height of the mercury column in a barometer is *lowered* by capillary forces.)

Suggested additional investigation

A valuable extension to this investigation shows how variations in porosity can occur. Set up a column of large beads (or pebbles) and determine its porosity as you did in the investigation. Mix in small beads (or sand) and ask the students if this time porosity will be greater or lower. The porosity is lower because the smaller grains fill the interstices between the larger particles.

8–4
Water moves into the ground.

The ways water enters different types of soil may become clearer to the students if you use an analogy. Imagine a child running through a hall filled with adults clustered in small groups. The child must make his way around the various groups, but he is slowed very little as he makes his way through the hall. The grouped adults are like soil aggregates that permit fairly easy passage of water. If the same number of adults were evenly spread out through the hall, it would take the child much longer, since his path would involve a great deal more dodging sideways.

Demonstration You can demonstrate how a layer of straw or vegetation on a soil surface protects the soil capillaries. Nearly fill two shallow wooden boxes loosely with a loam or garden soil. (You might instead use two stream tables from the Stream Table Kit.) Loam is a mixture of clay, silt, and sand in varying proportions. Cover the soil surface of one box with straw or dried grass clippings. Leave the soil surface in the other box exposed.

Using a watering can, sprinkle water into each box from a height of about one meter. After 15 to 30 seconds the impact of the drops should begin breaking the soil aggregates and spreading the particles over the surface of the box without the protective covering. Puddles begin to form because capillaries have been destroyed and water moves more slowly into the soil. Carefully remove the protective covering from the second box. Water should have passed into the soil easily without noticeable damage to the soil surface.

Several students can be assigned to experiment with this demonstration and then perform it in class. Sprinkling can height, sprinkling time, soil characteristics, and drainage beneath the boxes are all variables that may need adjustment to produce the results described above. Try to get the class to think of a natural situation to match the demonstration, no matter how it turns out.

The students may know about the use of contour plowing to deter runoff and promote infiltration. You can demonstrate the effect of contour plowing by tilting both boxes and scratching some parallel furrows in the soil of one box, 90 degrees from the direction of tilt. Leave the soil of the other smooth. After equal

sprinkling, the contour-plowed soil should show signs of less runoff than the uncontoured soil, because small ponds form in each furrow. See if the water soaks in after a while.

The effects of slope on runoff and infiltration can be demonstrated by tilting one box a great deal more than the other. Watch out for landslides.

Ask the students what effect man has had on infiltration. Large areas of the earth's surface that have been paved or built upon restrict the infiltration of water. Shopping-center parking lots are an example. What about water-table levels under large cities, such as Chicago and New York, where asphalt, macadam, concrete, and steel cover hundreds of square kilometers? Water-table levels beneath many large cities are permanently very low.

Discuss how slow infiltration can lead to flash floods, long-standing puddles, and water holes, and how sandy soils can produce rapidly-drying surfaces and subterranean water storage.

Demonstration You can demonstrate the presence of moisture in soil by heating a Pyrex test tube containing a little soil over a flame. Hold the test tube at an angle of 45 degrees to the table top. Water droplets will condense around the mouth of the test tube. Continue heating until the soil appears to be dry. Then wipe dry the mouth of the tube with a piece of cotton or gauze. Now heat the tube again and let the students observe that water droplets appear a second time. Soil moisture is present even in soil that seems to be completely dry.

8–5
Water is stored at lower levels.

A sponge is a useful device for showing the difference between capillary moisture storage and moisture stored as gravity water. If a sponge is squeezed and released underwater, it becomes saturated. This is analogous to gravity water stored in large pores in the soil. If the sponge is squeezed underwater and released in the air, it retains only capillary water. Air has replaced the water previously in the sponge.

The Text stresses the distinction between capillary and ground-water storage. You might mention that water from the water table is usually unavailable to vegetation. Plant roots must depend on water near the surface.

Demonstration A demonstration of water table fluctuation is easily set up using a glass aquarium, some sand, and an L-shaped glass tube. Tape the tube in one of the corners at the bottom of the aquarium so that the right angle of the tube is flush against a corner. The tube end pointing upward must be long enough to project above the top of the layer of sand. The end of the tube lying along the bottom of the aquarium should be covered with gauze. Attach a piece of rubber tubing to the upper end of the tube so that you can start a siphoning action after water is introduced into the system.

Cover the bottom of the aquarium with a layer of clean sand. The coarser the sand, the more satisfactory the demonstration will be, but it is important that the sand be of uniform particle size. Add water to the aquarium to about three-quarters of the thickness of the sand. As you begin the siphoning action, students will see the previously level water table slope down toward the siphon tube.

Answers to thought and discussion

1. How does vegetation influence runoff? **Answer** It generally reduces runoff in two ways: (1) It intercepts precipitation before it can strike the ground, reducing raindrop splash. This helps preserve soil aggregate structure and soil porosity. (2) It provides organic matter for the soil that acts like a sponge.
2. Distinguish between capillary water and gravity water. **Answer** Water that permeates large pores in the soil and moves downward under the influence of gravity is called gravity water. Water retained by soil particles due to surface tension is called capillary water.
3. How does a river continue to flow during dry spells? **Answer** Ground water storage systems discharge water into the river.
4. What happens to ground water storage during a drought? **Answer** During a drought ground water storage is reduced, and the water table is lowered. Sometimes the height of the water table is taken as an index to the severity of a drought.
5. Should the outlet of an artesian well be higher or lower than the intake area? **Answer** Lower,

if the well is to flow. The pressure at the outlet of the well is proportional to the height of the recharge area above the outlet of the well.

8–6
Evaporation and transpiration

Demonstration You can illustrate how transpiration takes place by letting the students examine a leaf stoma under a microscope. The biology teacher may be able to help with this demonstration. Many students enjoy identifying stomata on fresh leaves that they bring to school. (See Guide Figure 8–2.) Staining will highlight cell structure. Some schools have prepared microscope slides of these openings on the leaf.

Action Set up the transpiration activities with geranium plants and cacti in the classroom so that students can observe the moisture that collects in the plastic bag and the weight change that accompanies the release of moisture. Encourage the students to experiment with these and other plants at home or at school.

You may wish to review the physical causes and controls of evaporation and transpiration. Emphasize the fact that energy is required to evaporate water. Water need not be at 100°C in order to evaporate; it can evaporate at any temperature, even directly from ice. Evaporation at lower temperatures requires more energy.

Evapotranspiration. You may avoid this awkward word by using the term *water loss,* which implies the combined water losses to the atmosphere through evaporation and transpiration. Water loss is affected by temperature, humidity, and wind, but is not caused by them.

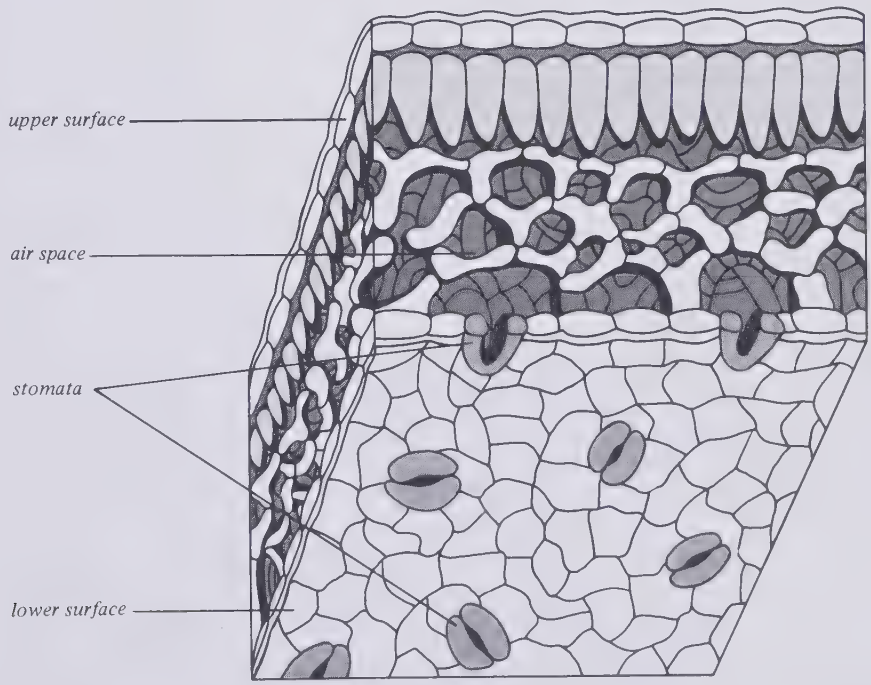
8–7
The water balance

The local water budget graphs (Figure 8–12) illustrate an accounting technique that is applied widely in earth science. The graph is a simple method of keeping track of moisture income and outgo for an area. It presents patterns of moisture usage, storage, recharge, and deficit. The "potential water loss" in Figure 8–12 is the maximum amount of moisture that *could* be given off by evaporation and transpiration.

Your students might be interested in seeing the *Water Resources Review* bulletins listed in the Supplementary Materials. If you want to expand the discussion of water budgets, the pamphlet *Basic Data and Water Budget Computation,* listed in Supplementary Materials, gives information on constructing the graphs.

8–8
Runoff

Mention at the beginning of this section that only about 25 per cent of the precipitation on the continents returns to the streams as surface



GUIDE FIGURE 8–2
Stomata open and close to control the exchange of water vapor and other gases between the interior of the leaf and the atmosphere.

runoff. Approximately 11 per cent returns as ground water flow to streams. Total streamflow, then, accounts for only slightly more than one-third of all precipitation. Evapotranspiration accounts for the remaining 64 per cent of the water that falls as precipitation.

You may want to have some students prepare reports on major floods in the United States or in other parts of the world. The 1966 flood in Florence, Italy, that damaged or destroyed art treasures throughout the city was extensively covered in newspapers and magazines, as were the widespread floods in the United States in 1972. Interested students also could investigate and report on factors underlying recent flooding either locally or in various parts of the world.

A student may wish to investigate the extent of the local watershed. A *watershed* is the area or region drained by a particular stream and all its tributaries. Watersheds or drainage basins are discussed in Strahler's *The Earth Sciences.*

Some of the nation's larger drainage systems have streamflow controlled by dams. Ask the students to compare the flood control value of dams and marshes or flood plains. What does each method do that the other cannot?

8–9
Investigating a flood

Advance preparation

Have graph paper to distribute to the class.

Time requirements

Pre-lab	5 minutes
Lab	20 minutes
Post-lab	40 minutes

Pre-lab discussion

Hold the pre-lab the day before you plan to do the lab and discuss the questions. Assign each student one of the four graphs as homework. Explain that the graphs should be smooth curves, not point-to-point lines. If students are unfamiliar with this technique of graphing, this is a good time to remind the class that some of the variation in the data is random or accidental. For this reason, it is good procedure to smooth the data by drawing lines that follow a mean or average value for clusters of points. A chalkboard sketch should clarify what you mean.

Notes on procedure

If the students have drawn the graphs at home, most of the lab can be used to discuss the answers to the questions from the investigation. You can use the students' graphs as a basis for the discussion.

Range of results

Student graphs should resemble the ones in Guide Figure 8–3.

Post-lab discussion

You can begin the discussion by asking students to describe the river basin in these graphs. It is a small headwater area where the river rises and falls rapidly following the rain. River forecasting techniques for the main stem of the river would have to be much more elaborate to predict the flood stages and flow if there were several tributaries.

Answers to questions

1. If the discharge doubles, do you expect the river stage to double? **Answer** No. See Graph II, Guide Figure 8–3. The curve is not linear. At some height the river flows over its banks, so the river stage increases less rapidly for the higher volumes of discharge. The extrapolated curve should have less slope than that indicated by the last two highest points.
2. What is the proportion of runoff to rainfall for storms of 5 centimeters? 20 centimeters? Why are the proportions different? **Answer** Graph IV, Guide Figure 8–3, shows that the proportions are 1 to 5 and 13 to 20, respectively. With light rainfalls there may be little or no runoff because of infiltration, interception by vegetation, and evaporation.
3. If the weather last month had been hot and dry, would you expect more or less runoff from the storm? **Answer** Less, because more rain would have gone to replenish the dry subsoil. However, the difference in this case would probably have been negligible, considering the enormous rate of rainfall.
4. What is the runoff from the predicted storm rainfall of 27.5 centimeters? **Answer** See Graph IV. Answers will differ depending on the way the curve in the graph is extrapolated. Beyond the first 10 or 15 centimeters, almost

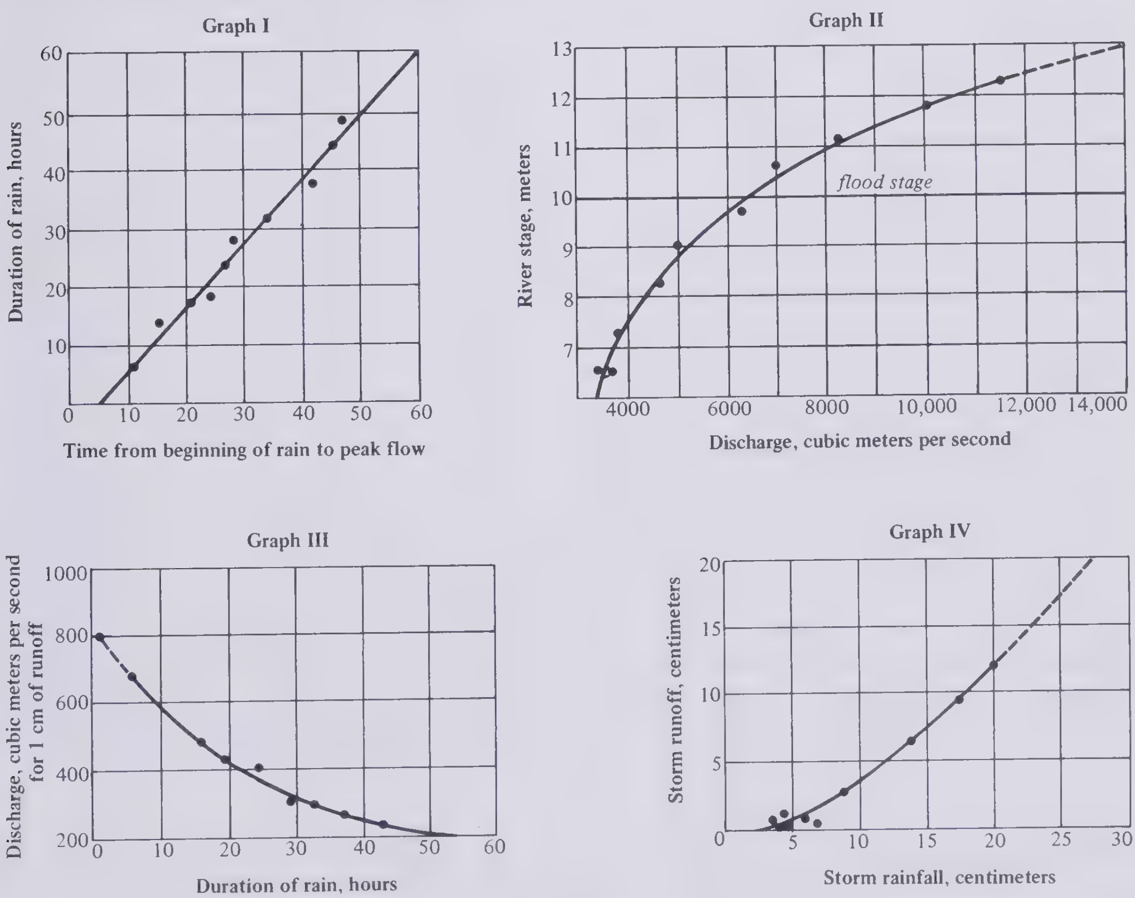
all the rainfall becomes runoff, and the curve can be extrapolated in a straight line extended through the highest two observed points. This extrapolation yields a runoff value of about 20 centimeters.

5. Assuming the storm lasts for five hours, how much discharge will the 27.5 centimeters of rainfall produce? **Answer** About 14,000 cubic meters per second. Graph III shows that the discharge is about 700 cubic meters per second for each centimeter of runoff for a storm lasting 5 hours.
6. How high will the river rise? **Answer** Depending on the manner in which the curve of Graph II is extrapolated, a height of roughly 12.8 meters, which is 2.8 meters above flood stage.
7. If the rain begins at 5:00 p.m., when will the crest occur at the gauging station? **Answer** At 6:00 a.m., about 11 hours after the beginning of the storm. See Graph I.
8. A sudden, violent flood after a storm is called a *flash flood*. Should you warn the people of the town now about a possible flash flood, or wait until the rainfall reports come in six hours from now? **Answer** The observed heavy rains and the predicted path of the storm would justify a warning of flash floods in the river basin headwaters as well as downstream at the gauging station.

8–10
Man changes the water cycle.

You might assign students to bring to class articles concerning man's effect on the water cycle. Such articles are frequently found in newspapers, magazines, or other sources. One way to discuss them is for each student to summarize an article for the class. Then ask the students to identify what change was made in the water cycle, what the effects might be, and who might benefit from the change. Strahler's *Planet Earth*, listed in Supplementary Materials, contains a good discussion of man's influence on the water cycle.

GUIDE FIGURE 8–3
Sample graphs using flood data from Investigation 8–9.



Answers to thought and discussion

1. Runoff takes place over the surface of the soil and also as ground water flow. What would you consider the most accurate way to measure the runoff from a river basin? **Answer** Runoff is the difference between precipitation and evapotranspiration. Because of the difficulty of measuring these quantities (especially evapotranspiration), determining the volume of water moving past stream gauges is the most accurate method of estimating runoff.
2. The seeding of clouds that are already overhead is a possible method of controlling the runoff cycle. If it were possible to produce precipitation reliably by this means, would it speed up the runoff cycle? **Answer** Probably yes, but any answer to this question remains speculative. The effects of weather modification on the larger-scale circulation patterns are not known, and it is possible that secondary changes could alter the climate toward either more or less rainfall and runoff. Increasing the rainfall in one portion of a river basin, for example, could rob an adjoining area in the same basin of precipitation.

Discussion of unsolved problems

Many ideas have been tried to make more water available for human use. Find as many examples for discussion as you can. Ask students what other effects might result from each attempt to modify the water cycle. Changes in the water cycle often will have wide-ranging effects on weather, crops, and animal life, to name only a few examples. If a discussion on reservoirs bogs down, you might ask, for example, how the reservoir might affect evaporation. Or ask how it might affect fish life, scenic values, or the water supply in towns downstream.

Influencing moisture storage in the atmosphere and ocean or changing the timing of elements in the runoff cycle are generally community, state, and federal considerations. There are many items in the news about large-scale water distribution projects.

Answers to questions and problems

A

1. What is the earth's main source of fresh water? **Answer** This is a question that will involve students in a reexamination of the water cycle. The ocean is certainly the major reservoir of water. From it the atmosphere acquires its moisture, so that the atmosphere becomes another reservoir for the earth's fresh water supply. As pointed out in the Text, the largest quantities of fresh water are stored on the land in the forms of ice and snow.
2. During what season of the year does the most precipitation fall? **Answer** In continental areas the largest amounts of precipitation fall during the summer. Over the oceans, precipitation generally is distributed evenly over the year, with a slight tendency toward maximum rainfall in early fall when the air-sea temperature differential is greatest. The lower layers of cold air moving off the continents are heated and the air mass becomes unstable. This sets up convection columns that carry moisture aloft where it condenses and produces precipitation.
3. What happens to the precipitation that falls on the earth? **Answer** Some of it evaporates, some runs off the surface of the land, and some goes into the ground where it is used by plants or enters the ground water storage systems.
4. What is a pore space in soil? **Answer** An opening between soil particles. In a dry soil pore spaces are occupied by air, and in a wet soil, by water. Rock layers may also be porous.
5. How is water held in soil? **Answer** By capillary action. Attraction forces between water molecules and soil particles hold water in the soil. Clay soils hold the most water because their particles are smaller and the number of capillaries between them is greater than in soils that consist of larger particles.
6. How is bedrock able to store ground water? **Answer** Bedrock stores water in the same way soil does — between grains. Generally, however, its porosity is not as great as that of soil. Sandstone usually makes the best aquifer, not necessarily because of porosity, but principally because greater permeability facilitates the flow of water within the rock to feed a well. Sometimes large quantities of water are stored in fractures within bedrock.
7. How is water that falls on the land returned to the ocean? **Answer** Some of it evaporates, some is transpired, and some of it flows off or under the land surface into streams that eventually flow into the ocean.

8. Where does the heat come from when water is evaporated or transpired? **Answer** Some of the heat comes from solar radiation and some from long-wave radiation from the atmosphere and the earth's surface.
9. In which season of the year are evaporation and transpiration highest? **Answer** During that season when the greatest amounts of water and energy are available. This is usually the summer season.

B

1. How do plants protect the soil? **Answer** Plants break the fall of raindrops and enable water to reach the soil without striking with great force. When the soil is unprotected, raindrops disrupt the surface and cause erosion. Plant root webs also help hold soil particles in place and maintain the pore spaces. Plants shade the soil surface and prevent it from drying into an impermeable crust.
2. What is the ground water table? **Answer** The ground water table is the *top* of the permanently saturated zone underground. It may be used as an indicator of the amount of water in storage. As surplus gravity water moves into storage, the level of the water table rises.
3. What is an aquifer? **Answer** An aquifer is any water-bearing layer. It may be unconsolidated material like sand or gravel, or it may be a porous rock layer.
4. How does an artesian system work? **Answer** Water entering an aquifer in an enclosed system will move great distances underground. As long as the intake level is at a higher elevation than the point at which a well punctures the artesian system, hydrostatic pressure will force water to move into the well. The rate at which movement occurs depends principally on the permeability of the aquifer and the pressure on the water in the system.
5. Why isn't there much runoff when it first begins to rain? **Answer** Most of the water fills the empty pore spaces in the soil or evaporates.
6. What factors govern the rate of penetration of water into the ground? In addition to those mentioned in the Text, can you think of any others? **Answer** Porosity and the condition of the surface are the factors mentioned in the Text. Additional factors are the soil moisture and the temperature of the water and the soil. For example, permanently frozen soils are relatively impermeable. The amount of organic material in soil also affects infiltration, since humus tends to soak up and retain moisture.

C

1. During humid periods in the spring, water condenses on snow surfaces. What effect does this have on the rate of melting? Do you think that this is a factor in spring floods? **Answer** The condensation of moisture on a snow surface increases the rate of melting because condensation releases heat. This in turn increases runoff and is often a factor in spring floods.
2. Can ground water flow uphill? Explain your answer. **Answer** Ground water, like surface water, cannot flow uphill unless it is under pressure, but it can rise to and spill over the rim of impervious underground basins.
3. Do you think that large streams or small streams would vary more during and after a rain? **Answer** A small stream varies more. It takes much less water to appreciably increase the flow of a small stream than to increase that of a large stream.
4. Would water evaporate faster from a pan of hot water or a pan of cold water? Do you think that there is any difference in the rates of evaporation from large deep lakes and small shallow lakes? **Answer** More water would evaporate from a pan of hot water because the energy of the molecules is higher and the molecular motion more rapid in hot than in cold water. Water would evaporate at a faster rate from a small shallow lake because the average temperature of the water is higher than that in a large deep lake.
5. Is perspiration in humans related to transpiration in plants? What is the main function of each process? **Answer** Yes, they are related. Both represent water removal. However, the energy for transpiration comes directly from the sun. Transpiration brings water from the soil to plant leaves so that photosynthesis may take place. Perspiration in humans serves an excretory and cooling function.
6. Are evaporation pans a good way to measure the loss of moisture from a region? Explain your answer. **Answer** Their usefulness is limited. When measuring moisture loss over a region, you must also consider soil cover, plant type, and color and texture of the soil.

Supplementary Materials

Reference books

Boys, Charles V. *Soap Bubbles and the Forces Which Mould Them.* Dover Publications, New York, 1959. (Paperback) Lectures delivered to a young audience in 1889–1890. Illustrates the forces involved in capillarity.

Davis, Kenneth S., and Day, John Arthur. *Water: The Mirror of Science.* Doubleday and Company, 1961. (Paperback) A philosophical essay on water. Excellent for the science teacher.

Strahler, Arthur N. *The Earth Sciences.* Harper & Row, New York, 1971.

Strahler, Arthur N. *Planet Earth.* Harper & Row, New York, 1971. The final chapter, "Man as an Agent of Change" brings together much of the current thought on this topic.

Walton, William C. *The World of Water.* Taplinger Publishing Co., New York, 1970.

Periodicals

Carter, Douglas B. *Basic Data and Water Budget Computation for Selected Cities in North America.* Prentice-Hall, Inc. (ESCP Reference Series-RS-8) A very comprehensive treatment of water budgets, including graphing instructions.

Maxwell, John C. "Will There Be Enough Water?" *American Scientist,* March 1965.

Penman, H. L. "The Water Cycle." *Scientific American,* September 1970.

Robin, Gordon de Q. "The Ice of the Antarctic." *Scientific American,* September 1962. (Also Scientific American Offprint #818.)

Sayre, A. N. "Ground Water." *Scientific American,* November 1950. (Also Scientific American Offprint #818.)

Wolman, Abel. "The Metabolism of Cities." *Scientific American,* September 1965.

Water Resources Review. Monthly issued by U.S. Geological Survey, Washington. Free.

Water Spectrum: Issues — Choices — Actions. Quarterly issued by Supt. Doc., U.S.G.P.O., Washington. $2.50 annually.

Films

Mountain Water. 17 minutes, color. U.S. Forest Service, 1952. Description of watersheds; brief introduction on flow, velocity.

Rivers in Miniature. 14 minutes, color. U.S. Army Corps of Engineers, 1961. Describes Mississippi Basin hydraulic model. Shows how floods are predicted and preventive measures taken.

Snow. 13 minutes, black and white. National Film Board of Canada, 1961. Good summary of origin and kinds of snow, causes of avalanches, and formation of (storage) ice.

The Trouble With Water Is People. 30 minutes, color. Columbia Broadcasting System. In depth study of the Colorado River watershed.

The Water Cycle. 10 minutes, black and white. Encyclopaedia Britannica Films. Food introduction for Unit II. Describes water cycle in detail with aid of animated diagrams.

Waters of Coweeta. 22 minutes, color. U.S. Forest Service, 1953. Study of hydraulic laboratory in North Carolina, demonstrating effect on flow of clear-cutting of timber, mountain farming, and woodland grazing.

unit three

The Rock Cycle

9. The Land Wears Away

Chapter Objectives

After completing this chapter students should be able to:

1. Explain what happens to rocks and minerals as they weather.
2. Recognize weathering products and discuss how they differ from the parent rock.
3. Describe how resistant minerals are separated from less resistant minerals.
4. Discuss how mature soils reflect the climatic conditions under which they formed.
5. Compare the erosive effects of water, ice, and wind on the earth's surface.
6. Describe the role of gravity in erosion.

Teaching the Chapter

This chapter discusses weathering, soil formation, and erosion. It develops in greater detail one essential theme of this course — the constantly changing surface of the earth. You can discuss how these changes affect the biosphere and man's environment.

Students investigate the role of moving water in erosion. They also discuss why water can erode more material than ice or wind. You can demonstrate that gravity is the force behind erosion.

The importance of weathering as a producer of soil is emphasized through an investigation. You should give special attention to the sections on the formation of soil and the relation of soil to plants and animals. Stress the fact that soils provide an important interface between the lithosphere and the biosphere.

Suggested time required

It should take about five to seven days to complete the investigations and discuss the topics in this chapter.

Section Notes

9–1
Weathering changes rocks.

Weathering probably is not a new word to the students, but they may not be fully aware of its geologic implications. Ask a student to explain what the word means. Other students may wish to add to or modify this definition. In this way a class discussion can give students a feeling for the term before they consider weathering in detail.

Show the students samples of weathered and unweathered rock. You can get suitable samples from almost any outcrop. Some of the rock samples provided for Investigation 2–3 have weathered surfaces and are also suitable. You might bring a geologist's hammer to class and ask students why it is such an important tool. It is used to expose a fresh, unweathered surface on a rock. The surfaces of most weathered rocks are quite different from their interiors. The most noticeable differences will be in color and texture. Weathering commonly masks the true characteristics of a rock.

Have students collect rock samples and compile a list of the changes produced by weathering. Perhaps you can use some of the rock samples that the students brought in during study of Chapter 2.

One way to remind students that weathering processes are not restricted to natural materials is to ask for examples or photographs of man-made structures that show signs of weathering. They may mention the deterioration of bricks and stones in buildings, loose mortar in brick walls, cracked sidewalks, peeling paint, rusty bridges, or the faded inscriptions on tombstones.

You may want to talk about the cost of weathering. Scientists are working to impede damage from weathering, sometimes by weather-

ing materials themselves. For example, iron is now being preweathered to give it a protective external layer of iron oxide. The coating prevents further oxidation of the metal beneath, much the way a coat of paint would.

You may want to review physical and chemical changes before discussing the differences between physical and chemical weathering. Almost any general science or physical science book will suggest simple demonstrations. Do not contrast physical and chemical weathering. Treat them instead as two closely related aspects of weathering. Students may be confused because the two sometimes occur at the same time.

If a cube one centimeter on each edge is cut into two equal rectangular blocks the surface area is 1⅓ times as great. If the cube is cut into eight blocks, the surface area is two times as great.

Demonstration To illustrate the effect of surface area on the rate of weathering, show the students two small calcite fragments (rhombs). Crush one of the calcite fragments in a mortar. Fill two small beakers three-quarters full of hydrochloric acid diluted seven to one. (Remember to add the acid to the water, not vice versa.) Drop the uncrushed rhomb into one beaker and have the students observe the rate at which it dissolves. Sprinkle the powder from the crushed rhomb into the other beaker and notice how rapidly it dissolves. (This demonstration also shows something about the chemical composition of the mineral, but that's not important here.)

Suggest that students check the effect of surface area on weathering by dissolving a sugar cube and an equal amount of granulated sugar in equal volumes of warm water.

9–2
Water — the universal solvent

How well students comprehend this section depends on how much they already know about the structure and characteristics of the water molecule. Start the discussion by asking some questions that review the water molecule's shape, dipolarity, and chemical activity. It will help to have on hand a model of the water molecule from Section 2–7.

The students may understand better how water contributes to chemical weathering if you call attention to common examples of weathering. The corrosion of automobile bodies in coastal areas, or in places where streets are salted to melt winter ice are typical examples. The corrosive effects are similar when mineral surfaces come into contact with dissolved salts in water.

Demonstration You can illustrate that carbonic acid (H_2CO_3) is an acid made when carbon dioxide is dissolved in water. Have students blow through a glass tube or drinking straw into a small beaker of distilled water containing a piece of blue litmus paper or another acid indicator. As the students breathe bubbles through the water, the litmus paper will turn red. This indicates an acidic solution.

Demonstration You can demonstrate how carbonic acid can dissolve calcite and limestone. Carefully determine the mass of several chips of calcite, then drop them in a bottle of carbonated soft drink that has been cooled in the refrigerator. Immediately recap the bottle tightly and leave it in a refrigerator for several days. Uncap the bottle and determine the mass of the dried chips. Are there any changes in the appearance of the chips? Add a few drops of a saturated ammonium oxalate solution to the carbonated drink. If calcium ions are present, a milky white precipitate will form. Where did the ions come from? Does a precipitate form in a fresh bottle of carbonated drink?

A "sun still" that uses solar energy to extract water from dry soil is available from Harbor Scientific, Box 2129, Costa Mesa, California 92626. You can use it to demonstrate the water film on soil particles, where most weathering occurs.

9–3
Investigating products of weathering

Time requirements

Pre-lab	5 minutes
Lab	15 minutes
Post-Lab	10 minutes

Materials

The following materials will be needed by each group of two students:

Earth Materials Kit, or:
- Soil sample, topsoil
- Soil sample, subsoil
- Granite, coarse-grained
- Granite, crushed, 10 ml

Magnifier from Teacher's Kit
Teasing needle
Plastic tubes with caps from Soil Profile Kit, 2
Water
Microscope (optional)

Pre-lab discussion

This works well as an open-ended investigation. Give groups the materials and tell the students how much time they have to make their observations.

Notes on procedure

Let students examine the samples in whatever detail they wish. Hand lenses, teasing needles and microscopes are useful. Some students may wish to wash the soil samples. This will let them see the larger particles more clearly, but it will double the time needed for the investigation.

After the students have shaken the soil samples in water and let them settle for a few minutes, have them record their observations.

Ask students to save the crushed granite.

Range of results

Students should have no trouble comparing the color and texture of the granite soil layers. They may be less certain about mineral composition because much of the weathered materials will be discolored by a coating of oxide. This will make it hard to identify minerals. However, students should still be able to distinguish quartz and mica fragments.

Post-lab discussion

The class's composite list of similarities and differences among the samples makes a good focal point for discussion. Variations in the observations of different students will be evident.

It should become apparent that topsoil does not develop directly from rock. The students should conclude that rock must first be broken down to fine particles by weathering. Then decaying organic matter can mix with weathered rock. The students should be able to generalize that each layer in the soil profile represents a greater degree of weathering than the one below.

Answers to questions

Examine the granite and the two soil layers.

1. In what ways are they similar? How are they different? **Answer** Similarities: Some of the materials may be present in all three samples. Each sample has some large and some small particles. Differences: Particles differ in color and size. Closer examination should reveal that one mineral, feldspar, is present in the lower layer more than in the highly-weathered top layer. Putting the samples in water should show that the relative content of colloidal-sized particles is different in the three samples.
2. Can you identify a mineral that exists in both the granite and the two soil layers? **Answer** Quartz and possibly mica could be evident in all three samples.
3. Which of the two soil samples that you have examined was taken from the top layer? **Answer** It will be apparent to most students that the fine material came from the top layer. Encourage them to explain why they think so. The top layer contains humus, which comes from dead plants and plant roots. It also is a different color. The topsoil contains smaller particles because it has been weathered more than the lower layers. The structure of the parent material (granite, in this case) is still obvious in the weathered granite sample.

Answers to thought and discussion

1. Why do rocks weather? **Answer** Rocks weather because their physical structures and the minerals they contain are reacting to a new environment.
2. How does physical weathering aid in chemical weathering? **Answer** Physical weathering aids chemical weathering by breaking rocks and exposing more surface area. The opposite is also true. Chemical weathering forms cracks and pits in rocks, making physical weathering processes more effective.
3. How is carbonic acid produced and how does it affect weathering? **Answer** Carbonic acid is produced by the combination of carbon dioxide and water. Carbonic acid releases

hydrogen ions (H^+) that attack and break down rock surfaces.

4. Why are many earth materials red in color? What element commonly produces color in earth materials? **Answer** The red color comes from the most common types of iron oxide. Iron combines with oxygen and water to form iron oxides that vary from red to yellow to blue. Another common coloring agent in rocks is manganese dioxide, which is black. Other chemical components of earth materials produce a variety of colors.

9–4
How soils develop

Figure 9–7 illustrates the development of a mature soil from the products of weathering. Make a transparency to use on an overhead projector during discussion. Mention that soil formation is a continuous process. The separation of stages is an artificial method that enables soil to be studied more conveniently.

Point out that the upper part of a soil layer one meter thick is in an environment much different from that of the lower part. Students may suggest a number of ways this affects the weathering process. For instance, the farther below the surface minerals are, the less intensely they are weathered. The soil material one meter below the surface will be less influenced by plant growth than soil near the surface. It will contain a lower percentage of organic matter. Water moving through the soil has maximum dissolving and leaching power near the surface. As the water moves downward, it becomes increasingly saturated with ions in solution. The soil leaches from the top down as water moves colloids from the upper soil layer to a lower one. Students may be able to think of other physical and chemical properties that will change from layer to layer. For example, if colloids accumulate, they will clog soil pores and decrease permeability.

9–5
Factors that influence soil formation

You can use Figure 9–9 as a basis for much of the discussion. One way to build on the theme of response to environment is to consider how each climate would influence the properties of soil layers. You can use material from the chapters about climate. The ideas here can be tied closely to the concept of the water budget as well. Ask, for example, if leaching takes place. How much leaching is there, and when during the year does it occur?

9–6
Kinds of soil

Students can use the map in Figure 9–9 to determine the type of soil in your location. Point out that the map is very general. Do the students agree with the map about the soil type in your location?

This is a good place to discuss the role of irrigation in modern farming. Water and soil conservation can also be introduced in this section.

Action This action will introduce students to one of the more important techniques of the soil scientist. Dig the trench carefully in order not to disturb the layers of soil. Good information related to this Action can be found in the ESCP pamphlet *Field Guide to Soils* (see Supplementary Materials).

Answers to thought and discussion

1. How does subsoil differ from topsoil? **Answer** Subsoil is rich in colloidal materials but topsoil is not. Most students will suggest the obvious difference that the topsoil is richer in organic material. Answers that mention the movement of colloids and color differences are acceptable.
2. What is the difference between mature and immature soils? **Answer** Mature soils have well-developed layering — particularly a layer of colloid accumulation. An immature soil does not yet completely reflect the environmental factors (like climate) that influence its development. Examples are most effective in making this point. You might ask the following question about a soil formed from granite: If you found fragments of feldspar in the topsoil, is the soil mature? The students should recognize that most of the feldspar would have been weathered out of the top layers of a mature soil. They observed this in Investigation 9–3.

3. In what type of climate would you expect rock weathering to be most complete? **Answer** Warm, moist climates.

9–7
Investigating stream erosion

ADVANCE PREPARATION

Make provisions for cleaning up spilled sand and water.

TIME REQUIREMENTS

Pre-lab	10 minutes
Lab	30–45 minutes
Post-lab	10 minutes

MATERIALS

The following materials will be needed by each group of three to six students:

- Trough, approximately 1 m × 5 cm radius, from Stream Table Kit
- Siphon tube with clamp, approximately 2 m × 1 cm in diameter, from Stream Table Kit
- Support to raise one end of trough
- Protractor from Globe Kit
- Gravelly sand, 500 ml
- Catch buckets, 2 or 3
- Timer
- Water

PRE-LAB DISCUSSION

You might begin by asking students to look at Figure 9–15 and decide which stream would erode more. What reasons do they give for their choice?

Discuss with students how they plan to investigate only one variable at a time. During the investigation what parts of the setup should they alter? What parts should remain unchanged?

When investigating the effect of stream slope changes, students must keep the volume of water constant. When investigating the effect of water volume changes, they must keep the slope constant.

NOTES ON PROCEDURE

The slope of the trough can vary from 0 to about 15 degrees. It takes from 5 to 30 seconds to erode the gravel.

Since students are trying to represent a natural stream, the water should be run into the trough above, *not on*, the gravel. When the trough angle is low, the gravel may not move. Tapping or shaking the trough gently can get it started. Several runs may be made before the catch bucket fills, but students should be reminded to empty the bucket before it becomes too heavy to lift easily.

RANGE OF RESULTS

Quantitative results will not be very accurate. Students still should be able to see that the rate of erosion is greater with increasing slope and increasing volume.

POST-LAB DISCUSSION

Most students expect slope and volume to affect erosion rate as they do. An interesting question to ask here is: Did changing the slope or changing the volume affect erosion more? The answer depends on how the student did the investigation, but the discussion should help the class arrive at an understanding of how each factor affects erosion rates.

Some questions you can ask to relate this investigation to natural streams are: Can a stream with a very low slope transport particles the size of gravel? Under what conditions? Which carries more sediment, a fast or a slow stream? A faster stream will have more carrying capacity than a slow one. The relative volumes of water must be known to determine which stream carries more sediment.

ANSWERS TO QUESTIONS

1. How does stream slope affect the rate of erosion? **Answer** The greater the slope, the greater the rate of erosion.
2. How does stream volume affect it? **Answer** The greater the volume, the greater the rate of erosion.
3. How did the different sizes and shapes of the particles affect their movement? **Answer** The small particles moved faster than the larger ones. The round particles moved faster than the flat or rough ones.
4. How could stream volume and stream slope change in nature? **Answer** Rain, melting snow, or tributaries increase the volume of a stream. During a dry spell, volume decreases. Stream slope may be changed by erosion, deposition, or crustal movements.

Suggested additional investigation

Project a transparency of Guide Figure 9–1, sketch it on the chalkboard, or distribute a copy to each student. Point out the physical features, soil type, and scale indicated on the map. Letters A through G locate real estate lots for sale. Ask students to decide which lot would be the best site for a vacation cabin. Other information, such as the size of the lake, the volume of the stream, the prevailing wind direction, the climate, and the vegetation, is not available. Students must decide only on the basis of what they can learn from the map.

You can have the class discuss the choice, or let small groups meet to pick a lot and then explain their choice to the rest of the class.

Site B probably will suffer least from erosion. G may become an island, while C and F are in danger of disappearing if the stream cuts a new channel. If the stream velocity is high enough A and D may erode badly. E is more protected than most of the others, but may be eroded by both stream and wave action.

9–8
Gravity — the force behind erosion

This section continues the concept of erosion as the response of weathered materials to gravity. Indirectly, even wind erosion is a response to gravity, since the movement of air masses results from gravity.

If you can, take the students to the site of local areas of soil erosion. Why is erosion greater there than at other nearby places? Where does the eroded material go?

How many times can the same material be eroded? Innumerable times. As long as it is not at the center of the earth's mass, material has potential energy that can be changed to kinetic energy by erosion. (See Chapter 3.)

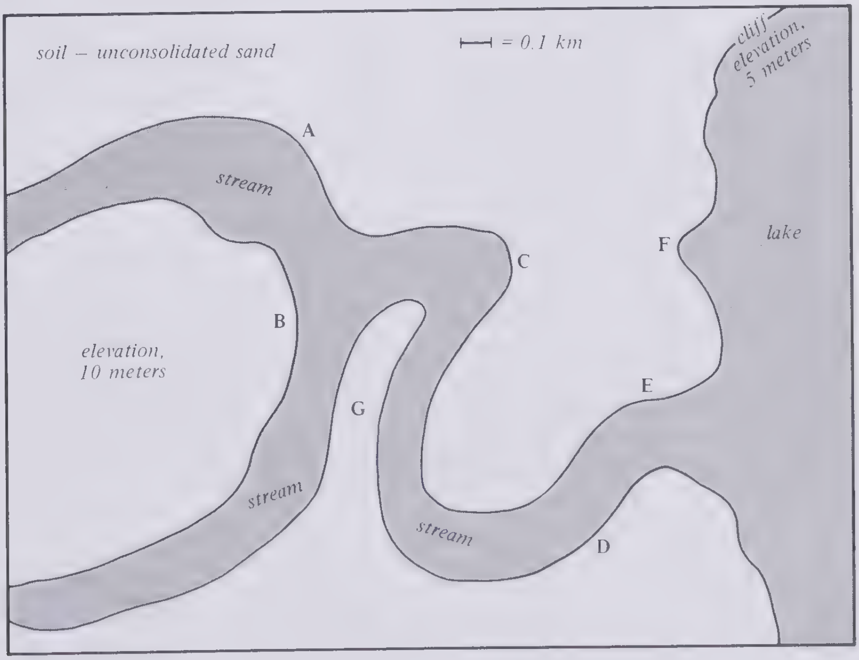
9–9
Water, ice, and wind erode the land.

The film *Erosion — Leveling the Land* illustrates the erosion process. *Evidence for the Ice Age* shows how glaciers move earth materials.

Students probably are most familiar with water erosion. You might develop the idea that water, ice, and wind can transport particles of widely differing sizes with the following demonstration.

Demonstration Fill the lower half of a cylinder with water and the upper half with motor oil. The less dense oil remains above the denser water. Drop a marble into the cylinder and watch what happens. Why does the marble fall more slowly through the oil even though the oil is less dense than water? Clearly, viscosity influences the marble's rate of fall.

Freeze a bar of ice approximately $45 \times 5 \times 2.5$ centimeters. Place the bar in a freezer, supporting each end on a block. The ice will bend slowly if a weight is placed in the middle of the bar.



Guide Figure 9–1 *Map of a lakeside resort area showing sites for vacation cabins.*

9–10
The magnitude of erosion

Demonstration Why is a raindrop a more powerful agent of erosion than a snowflake? High-speed photographs of raindrops striking should make this clear. Or you can demonstrate that a splash moves with force. To do this, drip water onto a hard surface covered with a fine layer of talcum powder. What happens? Refer also to Section 8–8 when you ask students to explain the importance of vegetation to water erosion in the desert.

Why isn't wind important to erosion in forests? One of the reasons is that trees break the force of the wind. Also, ground plants usually prevent dirt from being blown away. But a key answer is that emptyhanded wind can't do much eroding. The sculptured desert formations many students will think of were carved by water, or by windblown sand.

Answers to thought and discussion

1. What are the causes of erosion? **Answer** Wind, water, and ice are the geologic agents that erode the land, but gravity is the force underlying the process.
2. How are particles moved by each agent of erosion? **Answer** Streams carry sediment or products of erosion suspended in the water between the bottom of the stream and its surface. They also carry an invisible dissolved load. In addition, streams with very strong currents and steep slopes carry material along the bottom of the stream. Wind currents pick up loose surface materials and carry them along in suspension. When the wind dies down, the sediments are deposited. Ice can transport large particles, even boulders the size of a house, many kilometers. A glacier's load of large particles is deposited where the ice melts, although glacier meltwater is responsible for carrying certain fine-grained particles.
3. What is a "dust bowl?" How does it develop? **Answer** A dust bowl is an area that is being eroded severely by the wind. Dust bowls typically develop in areas where vegetation has been plowed under or killed by prolonged drought, leaving the topsoil unprotected.
4. How does erosion by glaciers differ from erosion by streams? **Answer** Streams of water sort their load of sediments according to size. Glaciers carry their sediments all jumbled together. House-sized boulders may be intermingled with cobbles, pebbles, and smaller rock fragments. When the sediments are laid down by the melting ice, they do not show the stratification or bedding typical of sedimentary rocks.

Discussion of unsolved problems

We are not sure what our ultimate impact on the environment will be. Perhaps all nations will have to work together to overcome man's far-reaching effect.

The rates of geologic processes will not be known with any accuracy until geologic events can be precisely dated. When the dates are known, scientists will be able to say, for example, how long it took a given land mass to be leveled.

The oceans and the moon are two frontiers that will provide additional information about weathering and erosion in different environments. The ocean is unique because the solid earth materials in it are not in contact with the atmosphere. The materials are transported in a denser medium than air. The moon is different because it lacks any permanent atmosphere and hydrosphere. If it occurs at all, weathering on the moon's surface will be due to marked temperature changes (as much as 100°C in a few minutes). The bombardment of lunar materials by cosmic radiation and meteoritic material can also cause weathering. Erosion on the moon would have to result from the action of gravity alone, without the agents that are at work on the earth.

Answers to questions and problems

A

1. What happens to rocks that are exposed to air and water? **Answer** The rocks undergo constant change as they weather chemically and physically.
2. Why is water such an important factor in weathering? **Answer** Water is an effective agent of chemical weathering because of its dissolving power. Water speeds physical

weathering by freezing and expanding in cracks.

3. How does weathering of rocks and minerals contribute to man's well-being? **Answer** Weathering dissolves nutrients, making them available for plant use. It also produces soil for plant growth. Other examples are possible.
4. What are the products of the weathering of granite? **Answer** Resistant minerals, ions, and colloids. The colloids will be composed primarily of secondary minerals that form when the minerals in the granite weather. Iron and aluminum oxides and clay minerals are examples.
5. How do mature desert soils differ from soils of forest regions? **Answer** The lack of moisture in desert regions results in soils that are only slightly weathered. Because they have not been thoroughly leached, such soils may be very high in minerals. In addition, the lack of vegetation in such areas means that there will be relatively little humus and nitrogen in the soil.
6. What is the role of gravity in erosion? **Answer** Gravity is the force causing the eroding agents, such as water, wind, and ice, to move materials.
7. How are materials moved by streams? **Answer** Ions are moved in solution. Colloids are moved in suspension. Larger particles are moved by bouncing and rolling in the water or along the stream bed.
8. Why is water able to transport larger particles than wind? Why can ice transport larger particles than water? **Answer** The more dense a material is, the greater its capacity to support and to carry particles at the same velocity. This means that water can transport larger particles than wind. Ice is actually less dense than water, but it is more viscous. This permits larger particles such as rocks to remain suspended in it longer and to be carried farther.

B

1. Why are almost all of the sand particles in the dunes around the Great Lakes or on the beaches of New England composed of quartz? **Answer** The mineral quartz is very resistant to weathering. It remains as residue when other minerals in the original rock have decomposed.
2. Colloids slow down removal of calcium from the soil by percolating water. Why is this process important for the growth of vegetation? **Answer** The negative charge of colloids attracts positive calcium ions in the soil. The two particles together are too large to be leached by the action of water. Calcium, an important plant nutrient, is then more likely to be available in the soil.
3. A limestone contains 10 per cent impurities, including some insoluble clay minerals. If this limestone weathers at the rate of 30 centimeters in a thousand years, how many years would be required to form 1.5 meters of soil? **Answer** In 1000 years, 30 centimeters would be weathered, but 3 centimeters (10 per cent) remain. Thus, $150/3 \times 1000 = 50{,}000$ years are required to form the soil.
4. Compare the velocity of a stream to the amount of dissolved chemicals the stream carries. **Answer** The amount the stream can carry in solution is not closely related to stream velocity.
5. How would you establish whether the soils in the area where you live were formed from bedrock or sediment? **Answer** You would have to look for the interface between the soil and the unweathered parent material. Good places to begin would be roadcuts, trenches, ditches, or other excavations that expose the underlying material. If the soil cover grades into solid rock such as limestone or granite, the interface is usually easy to recognize. It may be more difficult to recognize the interface between soil cover and loose sediment. Once this interface has been defined, however, soils formed from bedrock and from sediment are easily differentiated.
6. What evidence would establish that the loose material at a given location was a glacial deposit? **Answer** Since glaciers move materials of a wide variety of sizes, the loose material would be unsorted in both size and rock type. In addition, larger particles would have faceted surfaces due to the grinding action of the moving ice.
7. How could you tell whether a stream valley in the mountains was formed chiefly by a glacier or by running water? **Answer** Running water will tend to cut V-shaped valleys, while the grinding, scraping action of glaciers will tend to cut U-shaped valleys.

C

1. A cube with an edge of one centimeter is cut into 1000 cubes of equal size. What is the length of one of the small cubes? How much surface area is exposed by one of the small cubes? What is the total surface area exposed by the 1000 smaller cubes? If this were a cube of earth material, what effect would the increased surface area have on the rate of weathering? **Answer** With a cube length of 0.1 centimeter, the surface area per cube is: $6 \times 0.1 \times 0.1 = 0.06$ cm^2. The surface area for 1000 cubes is: 1000×0.06 cm^2 $= 60$ cm^2. The total surface area exposed to the weather has been increased from 6 to 60 square centimeters by cutting the cube. A cube of earth material divided into so many smaller particles would weather much more rapidly than it would have in the form of the single larger particle.
2. Would the weathering of 1.5 meters of limestone and the weathering of 1.5 meters of sandstone produce soils with the same thickness? Explain. **Answer** Limestone consists largely of calcium carbonate, which will dissolve or leach out. Sandstone is composed chiefly of quartz, which is very resistant to leaching. The cementing material in sandstone may or may not leach out. (Iron oxides are resistant, but calcium compounds are not.) Therefore, much less soil would be formed by the weathering of limestone.
3. Material on the top of a hill was found to be 30 per cent limestone fragments. Limestone bedrock exists 30 meters below the surface. The closest limestone deposit is 160 kilometers away. How could you account for the high content of limestone fragments in the soil materials? Assume that the material at the top of the hill had not weathered from the limestone bedrock. **Answer** The material may have been picked up by a glacier, then deposited at the top of the hill by water melting from the glacier. Or, it may have been deposited by a stream earlier in the valley-forming process.

Supplementary Materials

Reference books

Buckman, Harry O. and Brady, Nyle C. *The Nature and Properties of Soils*, 7th ed. The Macmillan Company, New York, 1969. Comprehensive freshman-level college text.

Dyson, James. *The World of Ice*. Alfred A. Knopf, Inc., New York, 1962. A good discussion of erosional effects of ice.

Gilluly, James, Waters, A. C., and Woodford, A. O. *Principles of Geology*, 3rd ed. W. H. Freeman & Co., Publishers, San Francisco, 1968. Good basic information.

Keller, Walter D. *Principles of Chemical Weathering*, rev. ed. Lucas Brothers, Columbia, Mo., 1959. (Paperback)

Leet, L. Don, and Judson, Sheldon. *Physical Geology*, 4th ed. Prentice-Hall, Inc., Englewood Cliffs, N.J., 1971.

Foth, Henry, and Jacobs, Hyde W. *Field Guide to Soils*, (Earth Science Curriculum Project Pamphlet Series). Houghton Mifflin Company, Boston, 1971. (Paperback)

Films

Erosion — Leveling the Land. 14 minutes, color. American Geological Institute — Encyclopaedia Britannica Educational Corp., Film, 1964.

Evidence for the Ice Age. 18 minutes, color. AGI-EBEC, 1964.

The Wearing Away of the Land. 10 minutes. black and white. AGI-EBEC, 1960.

What Makes the Wind Blow? 16 minutes, color. AGI-EBEC, 1964.

The Work of Running Water. 11 minutes, black and white. AGI-EBEC, 1961.

Understanding Our Earth: Soil. 11 minutes, color. Coronet Films.

10. Sediments in the Sea

Chapter Objectives

After completing this chapter, students should be able to:

1. Construct or describe a model of an ocean basin.
2. Contrast the depositional processes that take place near shore, on the continental shelf, and on the continental slope.
3. Construct a model of turbidity currents.
4. Cite reasons why deposition alone does not cause the earth's crust to sink.
5. Contrast sediments deposited on the continental margins and those in deep ocean basins.
6. Give examples of events that could change sea level.

Teaching the Chapter

Students already have observed how rocks are weathered and how the products of weathering are transported by erosion. In this chapter they follow these sediments to the sea and learn their eventual fate.

Investigations emphasize the comparative amounts of energy required to transport sediments of different sizes. The key observation students make is that the coarser materials are deposited first when the wind or water loses some of its energy.

Students apply this observation to several examples of important depositional processes in the sea. They refer to the investigations to explain the formation of continental margins and ocean basins. In addition, students discuss where deposits in the deep ocean come from.

This chapter begins the treatment of geosynclines, mountains formed from sediments in the sea. Chapter 11 continues the explanation of what happens to sediments in a sinking basin.

Suggested time required

It should take six to eight days to discuss the topics and complete the investigations in this chapter.

Section Notes

10–1
Investigating the deposition of sediments

Advance preparation

Use the Screen Sieves Kit or other graduated sieves to prepare sediments of five different sizes ranging from pebbles to fine silt. Be sure the sediment is sieved *thoroughly* so that the sediment fractions are as uniform in size as possible. Have a supply of unsorted sediment available as well. Any gravelly sand can be used as unsorted material.

Time requirements

Pre-lab	5 minutes
Lab	15–20 minutes
Post-lab	10 minutes

Materials

The following materials will be needed by each group of two students:

- Tube with cap or stopper from Plastic Column Kit
- Ring stand and clamp
- Sorted sediments, 10–20 ml each size
- Unsorted sediments, 100 ml
- Clock with second hand
- Water
- Screen sieves from Screen Sieves Kit

Pre-lab discussion

You can introduce this investigation by asking students to predict the effect of sediment size on

settling time. Will large or small particles settle faster? How would they verify their predictions?

Notes on procedure

Remind students to clamp the plastic tube securely to the ring stand. Before they fill the tubes with water, students should make sure that the bottom cap is tightly in place and the hose clamp is closed. Students should fill the plastic columns almost full of water.

One student from each group drops a pinch of sediment into the column while the other student times the settling rate. Encourage students to make a few trial runs to polish their dropping and timing techniques before the group begins recording data. Caution students to time the settling of the main body of sediment. Stray grains may settle faster or more slowly. Such grains are likely to have a different size or density than the rest of the sediment.

One way students can establish relative grain sizes is to compare each size to the smallest grains. They can refer to each sample in terms of how many times larger it is than the smallest grains. You may need to help students choose a suitable scale on the horizontal axis of the graph to show this size relationship. Guide Figure 10–1 shows one typical scale.

Don't insist that everyone use the same method. Students may think of another way to estimate grain size.

In the second part of the investigation, students should allow each additional handful of sediment time to settle before adding the next one.

Range of results

There will probably be a wide range of results because of the difficulty in measuring the settling time. However, the results will be similar to those in Guide Figure 10–1.

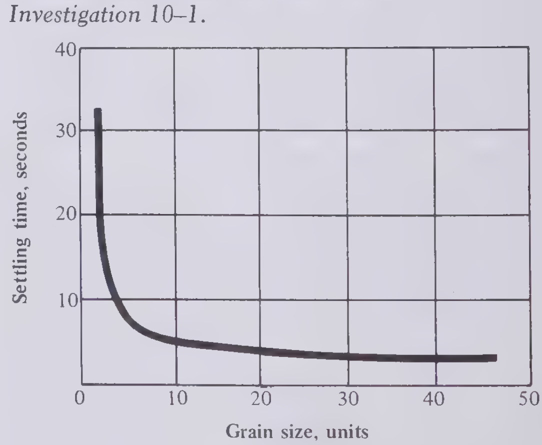
Post-lab discussion

Have the students interpret the graphs. If any graphs have a different overall shape, you might see if that group answered the questions in a way consistent with their data. You might ask students to predict what effect stirring the water would have on settling times. Would the grain sizes settle in the same order? How could you investigate this question? Some students may want to report to the class the results of this investigation.

Answers to questions

1. Is there a place on your graph where the slope of your curve changes markedly? If so, why do you think this happens? **Answer** Yes. The slope in most graphs has an elbow bend between two almost straight segments. Particles below a certain grain size are not heavy enough to force their way down through the water as easily as the larger ones, even though they are just as dense. Where this effect becomes almost as strong as the downward pull of gravity, the slope in the curve changes. The transition occurs over a range, not at a single point.
2. State the relationship between settling time and grain size. **Answer** The larger the grain size, the shorter the settling time.
3. Describe how these mixed sediments become arranged above the other sediments in the column. **Answer** Distinct layers of sediment of varying thickness can be seen. In each layer the larger particles are on the bottom and the smaller particles on top. This is called graded bedding.
4. Where in nature might you find deposits like those formed in this investigation? **Answer** Graded bedding occurs whenever flowing water carrying sediment enters quieter water. The sediment can no longer be supported and is deposited where streams enter lakes and ponds or where rivers enter the sea. Sand and gravel banks also can exhibit bedding that is sorted by size.

Guide Figure 10–1
Sample graph of grain settling time for Investigation 10–1.



10–2
Sediments reach the sea.

Ask students to identify some deltas and estuaries on a world map. Where does the Ganges River, shown in the chapter opener, reach the sea?

Where fresh and salt waters mix, a chemical process called flocculation increases the amount of sedimentation by making the grains of sediment larger. Ions from the dissolved salts cause fine particles to stick together.

Demonstration Since students have just investigated the effect of increased particle size on settling rates, you may want to demonstrate flocculation of colloid particles. Add five drops of aluminum chloride solution (44.4 g $AlCl_3$ per liter) or calcium chloride (55.5 g $CaCl_2$ per liter) solution to a large test tube two-thirds full of a clay suspension. Put your thumb over the mouth of the test tube and mix slowly by inverting. Flocculation occurs almost immediately if aluminum chloride is used. What happens to the clumps?

The examples of the Nile and Colorado River dams can be used to emphasize that changing one natural process will have many effects. What must be happening to the depth of the reservoirs behind the dams? What will happen to the dams if the reservoirs fill up with mud? The bottom of the Aswan reservoir is so sandy that much of the water leaks out. What do you think happens to this water? Will the estuary be more or less salty after a dam is built on the river? What happens to nearby crops if the ground water becomes salty? If nutrients are trapped behind the dam, will the fishing be as good at the river's mouth?

Students may be surprised that more of these consequences weren't foreseen. How does it happen that no one thought about the effects? Who decides to build a dam? What did the builders hope to accomplish? You might mention that some effects are hard to foresee. For example, after irrigation began, Egypt had a serious increase in a disease carried by snails. Many more snails could breed in the new network of warm irrigation ditches.

10–3
Sediments accumulate on the ocean floor.

The films *World Without Sun* and *Challenge of the Oceans* provide a good introduction to a study of the sea floor. They show the instruments and equipment used to investigate the sea bottom.

Students should examine the locations of ocean basins and continents on a world map or on a globe. One way to have students observe the uneven distribution of land and sea is to have a student put his face close to the globe at 10 degrees south latitude and 160 degrees west longitude. Have another student look on the opposite side of the globe, at 10 degrees north latitude and 20 degrees east longitude. Have the students explain to the class what they see.

Students may be misled by relief maps that have an exaggerated vertical scale. To help students appreciate how flat the continental shelf really is, have them try to plot it to scale. They will soon find that the slope, which is about two meters per kilometer, is so gentle that it is impossible to plot. The gentle slope of the continental shelf is flatter than the slope allowed for a billiard table. The slope of the continental shelf averages 0 degrees 7 minutes, while the specifications for a billiard table allow 0 degrees 25 minutes of tilt.

The shelf surface is so flat because both erosion and deposition occur there. Erosion levels the surface as changes in sea level cause the sea to advance and retreat. Deposition tends to fill in holes or depressions at times of high sea level when the shelf is covered.

One way to emphasize that changes on the deep ocean floor take place over extremely long periods is to contrast them with the rapid changes of shoreline environments. Change requires energy. Where is there a greater concentration of energy? Why is there so little energy available for erosion on the ocean floor?

10–4
Investigating turbidity currents

ADVANCE PREPARATION

The students will need a slurry for this investigation. Mix one part calcium hydroxide powder,

fine silt, or kaolin to four or five parts water. A slurry made from calcium hydroxide will only last for two or three periods. After a few hours you will have to mix another batch.

Time requirements

Pre-lab	10 minutes
Lab	20–30 minutes
Post-lab	15 minutes

Materials

The following materials will be needed by each group of two students:

- Tube with cap or stopper from Plastic Column Kit
- Ring stand and clamp
- Slurry material, 100 ml
- Test tubes, large, 2 or 3
- Water
- Clock with second hand
- Marking crayon, colored chalk, or lipstick

Pre-lab discussion

The theme of the discussion should be problem-solving. The investigation asks students to use their knowledge of density relationships, sediment transportation, and deposition to solve the problem: How do coarse land-derived sediments get so far out to sea? The Text told students that turbidity currents are suspected as the carrier, but they must find out if and how this occurs.

Notes on procedure

Students set up the apparatus as shown in Figure 10–9. The angle of the column should be between 25 and 35 degrees. Students can determine the column angle by using a large chalkboard protractor or an astrolabe. You may want each group to try a different angle within the recommended range.

The students must mix the slurry thoroughly, then pour it quickly into the column. Rapid pouring is necessary to get the entire slurry into the tube.

One student calls out five-second time intervals. The other one marks the position of the front of the slurry cloud on the column. After the cloud strikes the bottom of the column, students measure and record the distance traveled in each five-second interval. There is no need to measure the rate of each trial. Have them measure only every other trial.

Students can simulate an underwater canyon by pouring 10 or 12 more slurries into the column and letting them settle. This will put a layer of sediment down the sides of the column all the way to the bottom. As in actual canyons, disturbing the sediment can start a density current. Have students poke the sediment near the upper end of the column with a rod or wire. For approximately two-thirds of the groups, a turbidity current will start down the column.

Range of results

Students will find that the later slurries travel with greater velocities than the earlier ones, especially in the upper two-thirds of the tube. In addition, those groups successful in initiating a turbidity current by poking or disrupting the sediments often find that this one is the fastest of all.

Post-lab discussion

How well did student predictions agree with what actually happened as the density stream moved down the column? From their observations it should become apparent that the cloud moving down the column slowed down when the suspended material diffused into the surrounding water. This diffusion decreases the density of the cloud, which in turn decreases its velocity. Can the students explain why later clouds went faster? Turbidity currents pick up loose sediment from the surface over which they flow, becoming more dense and increasing in speed. (Refer to Investigation 4–7.)

Students may point out that this investigation is not a very good representation of an actual undersea canyon. The column has a smooth plastic bottom while the real canyon has loose sediment. In what other ways is this model like or unlike a real submarine canyon? In both places the turbidity current holds fine-grained sand and silt-sized particles. Coarser sand remains in the upper part of the canyon or column. As the sand accumulates, however, it is drawn along by the current. This may represent an erosive force that keeps submarine canyons open. Perhaps it even carves the canyons in the first place.

Return to question 4 of Investigation 10–1. Can students add another situation where graded bedding occurs? It occurs where a series of turbidity currents has deposited sediments.

1. Did the results of your investigation agree with your prediction? **Answer** Students generally predict that the earlier material will travel down the column faster than the later. It usually travels down the column more slowly. The later slurries often move faster because of the increased density caused by the turbid motion of the current picking up deposited sediment from the lower side of the tube.
2. Describe the speed and motion of the material as it travels down the column. **Answer** The slurry travels down the column with a billowy, turbulent motion. Its speed is greater at the start and decreases as diffusion causes it to become less dense. Larger particles may separate from the slurry and stay near the top of the column.
3. How do you suppose turbidity currents similar to the ones you produced are caused in nature? **Answer** Turbidity currents may be triggered by several processes that disturb the sea bottom. Earthquakes, volcanic eruptions, or boulders from a melting iceberg falling in the right place may be responsible. Even the motion of a creature that lives on the sea bottom may cause small currents.
4. How can turbidity currents carry coarse sediments far out into the ocean? **Answer** A turbidity current is able to support large sediments. Sediments too large to be carried are dragged along the floor of the sea. A turbidity current often picks up additional sediment as it moves along. Some students may realize that each time the density increases, the current speeds up and can pick up even larger sediments. This cycle enables turbidity currents to develop high velocities. One current in the Grand Banks, near Newfoundland, tore out two parallel telephone cables, allowing its velocity to be calculated as over 80 kilometers per hour. It is not hard to believe that currents with such speed and power can carry large sediments far out to sea.
5. Coarse continental sediments are found throughout the basins in the Atlantic. Why are they not found in the Pacific basins? **Answer** In the Pacific they go instead to fill the deep trenches between the continents and the plains. There are no trenches on the Atlantic side of the continent.

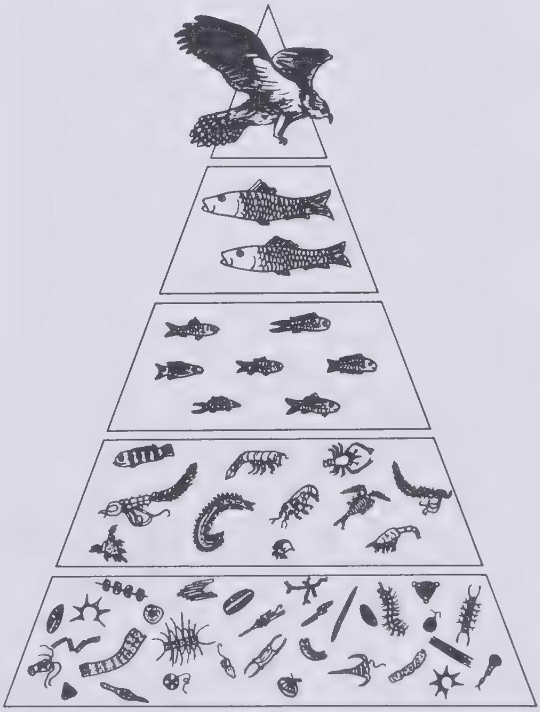
10–5
Some sediments form in the sea.
10–6
Minerals form in the sea.

The students may not be familiar with plants that have skeletons. Point out that diatoms are plants with glass-like skeletons. You can use a microprojector to show students examples of diatoms or foraminifera. You can get some from scientific supply houses if the biology department in your school does not have them.

One way to give students a feeling of how many tiny plants there are in the ocean is to draw a *pyramid of numbers* on the board. Guide Figure 10–2 shows a generalized pyramid. The shape of the diagram emphasizes that animals that eat animals are fewer in number than animals that eat plants. There are also more plants than plant-eaters. Assume there are ten times as many organisms on each step of the pyramid as on the step above. How many microscopic plants must be on the bottom of the pyramid to support the fish-eating bird at the top?

Manganese is a valuable mineral. How would students suggest that the deep sea nodules be mined? Does the necessary equipment exist?

Guide Figure 10–2
A pyramid of numbers. The organisms on each step feed on the organisms on the step below.



What might be some side effects of deep sea mining?

Answers to thought and discussion

1. Do all particles eroded from the land stop at the edge of the sea? **Answer** No. The greatest volume is transported to the continental shelf and slope. Some particles travel to the deep sea, and a few remain suspended in the water.
2. Where do the sediments at the mouths of submarine canyons come from? **Answer** They come from the beaches or shallow shelf areas near the heads of the canyons. They are carried by turbidity currents down the canyons.
3. Where do the materials come from that organisms use to make their shells? **Answer** The materials are in solution in the waters of the sea. Before that they were part of the rocks and minerals on land. Through weathering, they were dissolved and transported to the sea.
4. How do manganese nodules develop? **Answer** No one knows the complete answer. We do know that the manganese dissolved in seawater slowly precipitates out to form nodules around a pebble, bone, or shell.

10–7
The shorelines have moved.

A good way to introduce this section is to show the film *The Beach, A River of Sand*. Many of the topics in the section are illustrated in the film.

You might ask students if there is a specific force that enables beaches to migrate. The shoreline migrates only in response to rises and falls of sea level. Point out that these can be brought about by earth conditions other than glaciation. The period of the ice ages is used as an example in the Text only because the shoreline changes that took place then are well documented.

What other conditions can students suggest? Any process that changes the relative height of sea and land is an answer. You might add this example: The upward rebounding of the earth's crust in Scandinavia has exposed great areas of land during recent geologic time. Glaciers once depressed the crust in that region, but now their great weight is gone. This rapid rising of the land is recent enough to be included in the history of Denmark, Sweden, Norway, and Germany. To the Scandinavians, therefore, the sea level appears to be falling. To people in most other areas of the world the sea level is rising.

10–8
The thickening continental margins

A good way to discuss the Mississippi River delta is to have a group of students set up a river-delta-ocean situation in the stream table. Have the entire class watch while deposition and settling are taking place. You can call attention to the rate of deposition in different places. Do particles of the same size settle out of the river water at the same time?

With that tremendous amount of deposition in the region of the Mississippi Delta, why hasn't land been built faster? The great volume of sedimentary material is helping to cause the coastal area to subside. Only where deposition is faster than subsidence is there any apparent gain for the land.

This section begins the explanation of how a geosyncline develops. In Chapter 11 students will be introduced to the term and the rest of the complex process that makes mountains from sediments that accumulate in a subsiding basin. The purpose of this section is to acquaint students with the offshore areas where great thicknesses of shallow-water sediments have accumulated. Was the sediment deposited in the basin, or did the basin form as the sediment was deposited? You might ask students how they could tell the difference. The bottom layers should be a key.

Ask students to account for the fact that the five major basins mentioned in the section show little evidence of filling although there is a tremendous amount of deposition. This discussion should lead to the conclusion that these basins, like the Mississippi, are being depressed.

The frequent use of the Mississippi Delta as an example of deposition should not make it seem that deposition takes place only there. At the mouth of every river, large or small, sediment tends to accumulate, although a delta is not formed in every case.

Answers to thought and discussion

1. How would you prove that the shorelines of the oceans are not stationary? **Answer** You

could collect evidence that they are constantly changing in response to (1) erosion and deposition, (2) worldwide changes in sea level, and (3) readjustments of the earth's crust.

2. What do great thicknesses of sediment such as those found along the Gulf of Mexico indicate? **Answer** They indicate (1) a huge source of sediments, (2) a near-shore basin of deposition, and (3) a basin with a subsiding floor.
3. How do near-shore basins of deposition develop? **Answer** The sediments in the basin aren't as dense as the material beneath the crust that must have been displaced when the basin subsided. This means that the accumulation of sediments alone is not enough to cause a basin to subside. Other effects such as faulting and convection play greater roles in the development of near-shore basins. These will be discussed in Chapter 11.
4. How do glaciers influence changes in sea level? **Answer** As glaciers expand, they hold a lot of water in the form of ice. Consequently less water is available to the sea, and sea level will be lowered. As glaciers melt, water is released to the sea and the sea level rises.
5. How do the deposits of the continental shelf off the east coast of America compare with those in the Gulf of Mexico? **Answer** They are fundamentally the same. Differences arise from the source of material, climate, and thickness of deposition.

Discussion of unsolved problems

The origin of ocean basins must be closely related to the origin of continents. If we knew the origin of one, we could figure out where the other came from.

Basic to present thought about the origin of ocean basins is that they were formed before the continents. It is simpler to explain the origin of continental masses if the lighter continental material formed on top of the heavier oceanic material.

There have been many attempts to explain why thick sediments are lacking in the deep-sea basins. Perhaps an original 3000 meters of sediment compacted under its own weight to a layer 300 meters thick. To most people, a tenfold compaction seems unreasonable. Possibly some of the sediment has been changed to rock, and methods used do not measure the entire thickness. Or perhaps the oceans are younger than most scientists think.

The estimate of how thick the sediment layer should be is based on the hypothesis that the ocean basins are as old as the earth. Perhaps the present ocean basins are much younger. If the theory of continental drift (discussed in Chapter 11) is correct and the continents are moving apart, scientists may be measuring only the sediments that have accumulated since the drift began. According to this theory, Asia is relatively permanent and the Americas are drifting westward. If this is true, the Pacific basin is older than the Atlantic and should have more sediment. Instead it has less. Obviously none of these explanations fits the facts.

Answers to questions and problems

A

1. What happens to the settling speed of a particle of volcanic ash as it descends through the air and crosses the air-sea interface? **Answer** The settling speed decreases sharply. This is because water is more dense, and thus more buoyant than air.
2. Some submarine landscape features such as volcanoes and canyons show sharper outlines than their counterparts on land. How would you explain this? **Answer** On the ocean floor there are no weathering processes or agents of erosion (wind, streams, and glaciers) comparable in strength to those on land. Neither are there the temperature changes that help weather rocks on land.
3. What determines the rate of production of microorganisms in the ocean and the quantities in which they are deposited on the sea floor? **Answer** Two of the most important controls are the amount of nutrients available for the microorganisms to use and the rate at which they are feeding. The microorganisms stay in the top feet of the ocean because they also need energy from the sun. How many are deposited on the ocean floor will also be affected by the number of microorganisms eaten by other organisms. How many are deposited also depends on whether the microorganisms have skeletons that dissolve in seawater.

B

1. How do turbidity currents move and distribute sediment on the sea floor? **Answer** Turbidity currents and the sediment they contain move in response to gravity, because they are more dense than the surrounding water. When a current begins to slow down, the heavier sediments drop first.
2. What are some sediments that originate in the sea and how do they form? **Answer** Organic sediments are the remains of organisms that live in seawater. The greatest amount of these sediments comes from microorganisms with calcium-based (foraminifera) or silicon-based skeletons (diatoms). Chemical deposits originate when compounds dissolved in seawater form precipitates. This happens when some factor, such as temperature or salinity, changes and causes them to come out of solution.
3. How do you know that glaciers are not the only cause of changes in sea level? **Answer** Glaciers affect how much water is in the sea, but sea level also depends on how high the land is. Land building processes can change the level where land and sea meet.

C

1. The average thickness of sedimentary rocks in the earth's crust is about 0.74 kilometer. Assume an average rate of deposition of 40 millimeters per 50,000 years. Assume that this rate has been uniform for millions of years. How long did it take to accumulate the sedimentary rocks of the crust? Does your answer equal the total time elapsed since the deposition of the first sedimentary rocks? Why or why not? **Answer** First, find the number of millimeters of sedimentary rocks in the crust.

$$0.74 \text{ km} \times 10^3 \text{ m/km} \times 10^3 \text{ mm/m} = 740{,}000 \text{ or } 7.4 \times 10^5 \text{ mm}$$

Then divide the total amount by the deposition rate.

$$\frac{7.4 \times 10^5 \text{ mm}}{40 \text{ mm}} \times 5 \times 10^4 \text{ years} = 9.25 \times 10^8 \text{ or } 925{,}000{,}000 \text{ years}$$

No, the figure does not represent the total time. Some of the first sedimentary rocks changed over time into metamorphic and igneous rocks. Many were eroded, and the material used to make new rocks.

2. It is believed that some submarine canyons may have been carved by rivers that flowed across the continent. How could this happen? What evidence is there that all these canyons were not produced in this way? **Answer** If sea level were lower than it is today, rivers would extend across the present continental shelf. They would carve canyons there just as they do on the present land surface. Most canyons, however, extend to depths in the sea that seem never to have been above sea level. Some other process must have carved them.

Supplementary Materials

Reference books

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Engel, Leonard and the Editors of Life. *The Sea*. Time-Life, Inc. (Life Nature Library), New York, 1969.

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Dietz, Robert S. and Walter P. Sproll. "Equal Areas of Gondwana and Laurasia." *Nature*, December 10, 1966.

Fairbridge, Rhodes W. "The Changing Level of the Sea." *Scientific American*, May 1960. (Also Scientific American Offprint #805.)

Heezen, Bruce C. "The Original of Submarine Canyons." *Scientific American*, August 1956. (Also Scientific American Offprint #807.)

Wilson, J. Tuzo. "Continental Drift." *Scientific American*, April 1963. (Also Scientific American Offprint #868.)

Films

Challenge of the Oceans. 27 minutes, color. McGraw-Hill Text-Films. Discussion of oceanographic studies, methods, and instruments.

The Beach, A River of Sand. 20 minutes, color. American Geological Institute — Encyclopaedia Britannica Educational Corp.

Ocean Basins. 16 minutes, color. Lamont Laboratory, Columbia University. Marine Science Film Series.

Science of the Sea. 19 minutes, color. International Film Bureau. Summary of research projects and procedures.

World Without Sun. 93 minutes, color. Trans-World Films, Inc. Study of world below sea surface. Produced, directed, and narrated by Jacques-Yves Cousteau.

Other aids

Oceanography Filmstrip Series. Encyclopaedia Britannica Educational Corporation and Macalaster. "Geological Oceanography" and "Ocean Engineering" are most appropriate. Others in series that could be used are: "Physical Oceanography," "Chemical Oceanography," "Biological Oceanography," "Marine Resource," "Air-Sea Interaction," and "A Career in Oceanography."

Geological Society of America distributes wall charts showing physical features of ocean basins. For information and prices write Geological Society of America, 419 W. 117th St., New York.

Time, Inc. publishes wall charts showing physical features of ocean basins. For more information on these wall charts, write Time, Inc., Time-Life Building, New York.

11. Mountains From the Sea

Chapter Objectives

After completing this chapter, students should be able to:

1. Describe how mountains develop from geosynclines through the stages of deposition, deformation, and uplift.
2. Explain how mid-ocean ridges, deep-sea trenches, earthquake activity, and geosynclinal mountains might be caused by movements of the earth's crust.
3. Compare modern areas of shallow-water deposition with ancient geosynclinal basins.
4. Locate belts of crustal mobility on a globe and explain why they are seldom in the middle of continents.
5. Describe some basic causes of crustal unrest within continents and ocean basins.

Teaching the Chapter

This chapter exposes students to a progression of important geophysical theories. It begins with the early theories about geosynclines and finishes with drifting continents and the theory of plate tectonics. It is a meaty chapter that may raise more questions than it answers.

The chapter concentrates on the patterns of movement in the earth's crust. Earthquakes, volcanoes, and other dramatic evidences of crustal movement are exciting topics to explore in great descriptive detail, especially since they are also geological clues to activity in the earth.

For the investigations in the chapter students practice reading charts, making graphs, and interpreting maps to reach their conclusions.

Suggested time required

About five to six periods will be required to complete the investigations and discuss the topics in this chapter.

Section Notes

11–1
Investigating inland marine sediments

Advance preparation

Have graph paper on hand to pass out to the class.

Time requirements

Pre-lab	5 minutes
Lab	20 minutes
Post-lab	10–15 minutes

Pre-lab discussion

In this investigation students use a table in the Text as a source for information. You might ask your students whether they feel using second-hand data is as "scientific" as gathering their own? Which do they prefer? Can they suggest situations where scientists rely on others to collect data?

Notes on procedure

The construction of the cross section is a simple graphing exercise. The students should have little trouble completing it if they understand that for each of the stations in Figure 11–3 the thickness of Unit I extends from the surface downward. The thickness of Unit II extends from the *bottom* of Unit I downward.

The students should plot these thicknesses to the horizontal scale of the map shown in Guide Figure 11–1. Do not insist on any single vertical scale for the cross sections so that you can point out how different the same data may appear if the students choose several different scales. The difficulty of scale representation can be brought out by asking some of the students to plot the cross section to true scale. To do this they make a graph that has the same scale for both vertical and horizontal directions.

Range of results

The graph can be drawn to any reasonable scale that the student might choose.

Guide Figure 11–2 shows two cross sections, one with a vertical scale of 1 cm:1000 m and the other with both scales equal (line at bottom). This portion of the investigation shows that at a true scale, features many thousands of meters thick are hardly noticeable. When the perspective is the entire earth, mountains and the tremendous thicknesses of sediment seem insignificant.

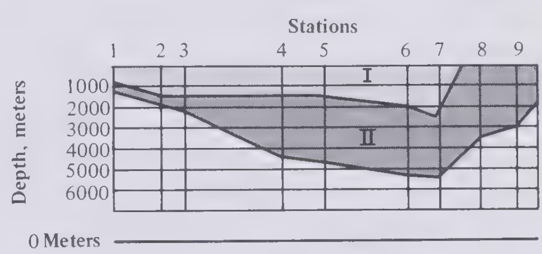
Post-lab discussion

Concentrate on discussing the graphs and the questions at the end of the investigation. It would also be useful to compare the photographs in Figure 11–2 to stations 8, 9, and 10. The obvious deformation of the sediments that has so altered their appearance helps explain the zeroes and question marks in Figure 11–3. Students may add that the deformation also makes it difficult to measure thickness.

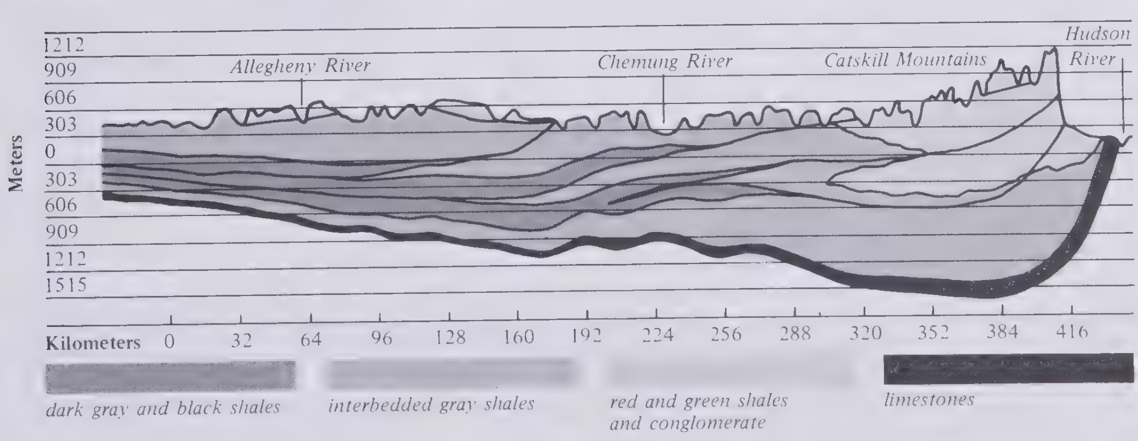
Answers to questions

1. What evidence is there in the photographs that these rocks are marine sediments? **Answer** Many of the rocks show layering and fossils of animals that are thought to live only in salt water. The layering and fossil remains indicate (but do not prove) that these are marine sediments. River deposits and other terrestrial deposits such as loess (wind-blown deposits) are also layered and may contain fossils. The subject of fossils is treated at

Guide Figure 11–2
Two sample cross sections of the rock layers. The line at the bottom is the cross section drawn with both scales the same.



Guide Figure 11–1
Geological cross section of the rock layers between Buffalo and the Hudson River.



greater length in a later chapter. Refer back to Chapters 6, 9, and 10 if some support is needed for the idea that sediments are deposited in horizontal layers and that the nature of the sediment indicates its origin. Chapter 16 will develop some of the proof more fully.

2. Describe the general shape of the basin shown by the cross section. **Answer** The western half of the basin thickens from west to east. The configuration is similar to that shown in Figure 11–6, which shows areas of deposition on the Gulf Coast and the Atlantic Coast.
3. How can you explain the rock types at the last stations as compared with those that were found at the first stations? **Answer** The rock types at the last stations seem to be deformed and highly disturbed. The students may volunteer the idea that these rocks were squeezed and broken or even melted.

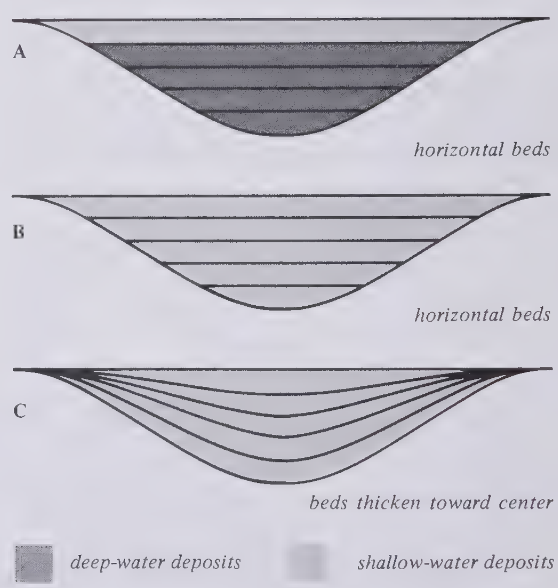
11–2
The layers of geosynclines

It will be helpful here to make a blackboard sketch or overhead transparency showing a cross section of a simplified geosyncline patterned after Figure 11–8. Use different colored chalk for different sedimentary layers. In class discussion you might go over the possible ways to fill a basin depicted in Guide Figure 11–3.

To help students visualize a sinking basin constantly being filled with sediments, ask students if they have ever seen automatic dish-stacking devices like those used in some cafeterias. As the plates are stacked one on another, a spring compensates for the additional weight and leaves the top plate at about the same height.

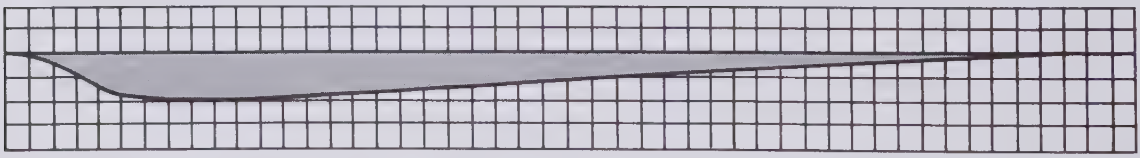
Some geosynclinal mountains, such as the Himalayas, are not *now* at continental margins. This was not necessarily so at the time the deposits were laid down. What has happened since might be accounted for by the concepts of spreading sea floors and plate tectonics discussed in Sections 11–11 and 11–12.

Students may wonder how scientists know about the contents of deep geosynclines when the deepest bore holes extend only a short distance into the earth. Direct observations of deep geosynclinal layers is possible where the layers were tilted upward or folded, then eroded crosswise through the layers. Although they cannot



Guide Figure 11–3
A *A deep basin fills with sediments.* B *A shallow basin fills as water and sediment levels rise together.* C *A basin under shallow water sinks as sediments fill it.*

Guide Figure 11–4
A geosyncline drawn to scale for the Action in Section 11–3



examine its lower contents, scientists conclude by inference that the basin contains similar materials throughout its depth.

11–3
Modern geosynclines

Have students find on the relief map of the world regions where continents are being washed into basins by major rivers. Areas considered to be geosynclines by some geologists include the Gulf of Mexico, the offshore parts of eastern North America, the Mediterranean Basin, and the Japan Sea area. Offshore volcanic activity is often considered to be characteristic of geosynclinal development. This would seem to hold for both the Gulf region and the Japan Sea area.

You might ask students if the areas thought to be modern geosynclines are likely to appear as mountains in the future. The implication is, of course, that they will appear as mountains if the areas are indeed geosynclines.

Action A geosyncline drawn to scale is shown in Guide Figure 11–4.

Making a chart on the blackboard is one way to emphasize the connection between where a rock was formed and what it looks like. You might begin by listing some features of sedimentary rocks and asking the students to describe the kind of place in which they might have formed. Then ask for a place where similar conditions exist today. An example appears in Guide Figure 11–5.

11–4
Deformation within geosynclines

Discuss the properties of solids. Ask students for examples of materials that respond to similar stresses in different ways such as breaking, bending, or flowing. Base your discussion on observation rather than analysis.

If it has been shown already, refer students to the ESCP film *How Solid Is Rock?*. If not, show it at this point.

Roll some Silly Putty into a sphere and then flatten or stretch it. Since the students have witnessed the deformation, they will know that you have deformed the sphere. Ask them if a student in the next class will say the same thing if he is shown only the flattened shape. This may lead to some discussion of how the original shape of a material can be determined.

Where appropriate, refer students to the James Hall field trip, Investigation 11–1, for evidence of intense changes in rocks found close to the center of a geosyncline.

Show students examples of deformed and undeformed rocks near your school, if possible. For showing large-scale deformation, Lobeck's *Physi-*

GUIDE FIGURE 11–5
Sample chart showing where features of sedimentary rocks might be formed.

FEATURE	A POSSIBLE ENVIRONMENT	PRESENT LOCATION
Layered rocks	Underwater deposition	Behind a dam
Ripple marks	Shallow water	Beach, low tide at La Jolla, California
Mud cracks	Shallow water (drains out)	Aftermath of a flood in Los Angeles
Limestone deposits	Shallow ocean water	Bahama Banks, Gulf of Mexico
Sandstone deposits	Beaches, more active streams	Atlantic City, New Jersey
Gravel deposits	Active mountain streams, foot of cliff at beach	Swift River, Maine
Marine animals (fossils)	Ocean, near shore (if crustacea)	Most seashores
Coal deposits	Swamp, alternate sea flooding	Great Dismal Swamp, Virginia and North Carolina

ographic Diagram of the United States and the accompanying illustrations are excellent. Books on physiography and geomorphology are also useful, including those by Atwood, Fenneman, Lobeck, and Thornbury. (See Supplementary Materials.) Each one has diagrams, photographs, and a discussion of bedrock structures in various parts of the United States. They will help students become acquainted with the types of deformation typical of their own region. It will also help them see the relationship between deformation and surface configuration.

Students may have trouble imagining rocks bending without shattering. See if you can find a very old stone or concrete bench that has sagged under its own weight. Show them the bench, or bring a photo to class.

Answers to thought and discussion

1. What evidence did James Hall have for his idea of a shallow depositional basin? **Answer** In the sedimentary rocks examined by James Hall, he saw coarse sand layers with ripple marks and bedding that were identical to similar sands on modern beaches. Whenever he encountered fossils, they were similar to animals now living in lagoons, estuaries, and on the shallow continental shelf.

   Intermingled with the sands and the fossil-bearing layers were both fine-grained and coarse-grained rocks that represented deposits formed in mudflats and along rocky sea cliffs.

   Nowhere did James Hall encounter sedimentary rocks containing fossils or sedimentary particles that are commonly recovered today from the bottom of the deep sea.
2. Why are sediments in geosynclines so thick? **Answer** The basin must have been sinking at about the same rate the sediments were being laid down. Otherwise, the sea basin would have filled up with sediment and the process would have stopped. If the basin had sunk faster, the sediments would not show evidence that they were deposited in shallow water.
3. Why do continental margins tilt toward the ocean basins? **Answer** Most of the fine sediments are deposited on the continental slope and rise. Slides and turbidity currents add the sediments on the slope to those that went directly to the rise. As the load grows, the crust under the continental margin begins to sink in response to the tremendous weight.
4. What happens to rock layers when they are squeezed? **Answer** Usually they break. If rock is under great amounts of pressure, perhaps combined with heat, rock can bend, stretch and fold. The original layers may be very hard to detect. Their thickness and composition will be changed.

11–5
Investigating earthquakes

Advance preparation

For weeks the students have been plotting the distribution of earthquake epicenters on the world map. The data is now available to generalize on (1) the global distribution of earthquake epicenters, and (2) the relationships between earthquake focuses and surface features.

Time requirements

Pre-lab	5 minutes
Lab	15–20 minutes
Post-lab	15–30 minutes

Materials

The following materials are needed for each class:

Marking crayons
Transparent plastic or tracing paper
Graph paper
Epicenter map from Earthquake Watch Kit

Pre-lab discussion

Before the students begin making their graphs, you might want to review the procedure the class followed in plotting the epicenter locations. This will emphasize the different kinds of information represented by each map pin. The class may have noticed some general patterns developing during the Earthquake Watch. Students can compare their preliminary observations of earthquake-prone regions to their completed analysis in the post-lab discussion.

Notes on procedure

You may have the students present oral reports on earthquake patterns to the class or hand in a written report to you. You can also put cross sections by students on a transparency for an

overhead projector and use them when the class discusses the results.

Range of results

The graphs will vary depending on the location chosen by the student, but a typical example is shown in Guide Figure 11–6.

Post-lab discussion

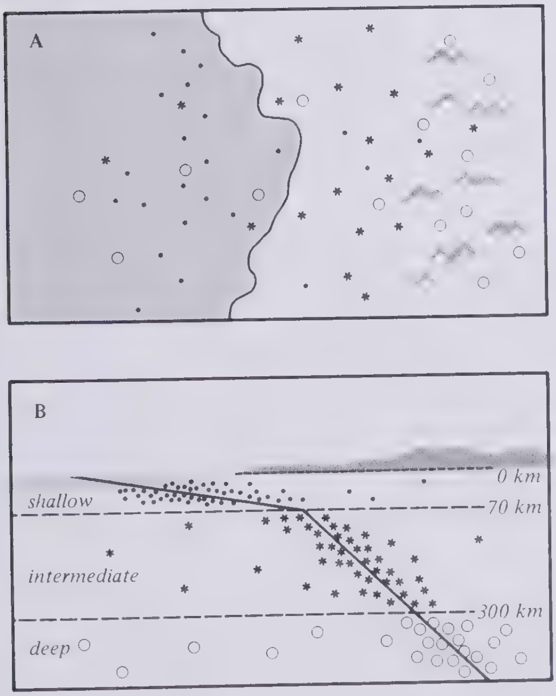
Encourage the students to describe the patterns developing on the map. Ask them which areas of the world are earthquake-prone and which are quiet and stable. The earthquake epicenters that border the Pacific Ocean, including the western United States, should be immediately obvious. Other areas, such as the Mediterranean region and the mid-ocean areas, are also prominent.

Does your locality have a history of earthquakes? Have any students read about crustal movements that make earthquakes probable in your area? How might you reduce the chances of being injured if you were in an earthquake? Ask any students who have been in earthquakes to describe the experience.

Answers to questions

1. What is the general pattern of earthquake distribution? Does it resemble or coincide with any other major patterns of the crust? **Answer** The earthquake activity of the world occurs around the Pacific Ocean and adjacent continents, and across the Himalayan chain to the Mediterranean Basin area. There is also a line of activity along the middle of several ocean basins. The pattern coincides with the distribution of volcanoes, major rift zones, and with young, rugged mountains in which movement still seems to be taking place.
2. If so, can you relate these features to earthquakes? **Answer** These are all associated with mobile regions of the crust. As data accumulates, it may become evident that earthquakes are always associated with mobile regions.
3. Where did the greatest number of earthquakes take place? **Answer** Geographically, the earthquake ring around the Pacific should be prominent, but concentrations of focuses should also occur in other mobile regions of the earth's crust. There is usually a higher number of shallow- and intermediate-focus earthquakes than deep-focus earthquakes.
4. How do you interpret the pattern? **Answer** Student answers will vary. However, seismologists believe that zones of weakness in the crust border many of the continental regions. These zones of weakness slope underneath the continental masses in the manner shown by the focus plots the students make.
5. Using Figures 11–5 and 11–13, describe the distribution of earthquakes with respect to (a) volcanoes and (b) mountains that have been uplifted from geosynclines. **Answer** All great earthquakes seem to be concentrated in zones of mountain-building activity. In some cases the activity seems to indicate the early stages of mountain building (as in the island arc areas and the Mid-Atlantic Ridge). In other areas the activity seems to accompany the late stages of mountain building (as in the Rocky Mountains and the California Coast Ranges).

Guide Figure 11–6
Map and cross section showing the typical distribution of focuses in the Earthquake Watch.



Suggested additional investigations

If any students would like to continue the Earthquake Watch, you might suggest that they record the actual depth (in kilometers) of each focus. Results might look similar to Guide Figure 11–6. This gives a better fit in the cross sec-

tion graph than is possible using only categories of depth. The students might also wish to plot the variation of magnitude with depth.

11–6
Island arcs and volcanoes

Students have already identified possible sites for present geosynclinal development. After the class has read Section 11–6 and noted how volcanoes are related to island arcs, see if they can delineate the island arcs of the Pacific.

Remind students of the stages of development associated with geosynclines — deposition, sinking, deformation, and uplift. Ask them to determine in which stage volcanic activity would be most prevalent. Apparently, volcanism can accompany any stage in geosynclinal development, but it occurs most frequently during the early and final stages. Basaltic lava is found interlayered with the sedimentary rocks of some geosynclines. This indicates that lava poured out onto the floor of the sea while the basin was sinking. Other geosynclinal mountain systems show accumulations of lava that evidently formed late in the cycle. It probably accompanied a stage of uplift and faulting.

Surtsey: The New Island in the North Atlantic and the film *Volcano Surtsey* have some of the best recent photographs of a spectacular volcano. They are listed in the Supplementary Materials.

11–7
Ocean trenches
11–8
Mid-ocean ridges

Demonstration To dramatize the height of some of the mid-ocean peaks and trenches, you might submerge the plastic model from the Contour Model Kit in an aquarium. How does its height, about 1000 meters, compare to ocean depths that exceed several thousand meters? Project a transparency of Figure 11–17 when you discuss similarities and differences between features above and below sea level. It is important to remind students of the great vertical exaggeration used in the drawing.

One way to help students compare areas of compression and tension in the earth's crust is to draw the mid-ocean ridges and rifts on the same map you used to show geosynclines in Section 11–3. You may find it useful to refer to this map again when the class discusses plate movements in Section 11–12.

The Heezen and Tharp maps listed in Supplementary Materials are views of ocean basin topography similar to the Lobeck map for the land. Shelves, ridges, faults, and volcanoes are well defined.

11–9
Other crustal movements

Transparencies of Figures 11–19 and 11–21 will help you guide discussion of this section. You might begin by asking one student to explain to the class what has happened in each stage of Figure 11–19. Do the same for Figure 11–21. Perhaps another student could draw on the blackboard a similar sequence of stages to show the simultaneous sinking and building of the Hawaiian Islands.

11–10
Stable and mobile regions

This section summarizes the development of geosynclines as part of a pattern of mountain building which affects the growth of continents. Point out that granitic, or continental, rocks include many types other than granite, while basaltic, or oceanic, rocks include types other than basalt. Review the Earthquake Watch map and compare the mobile belts and stable regions with the overall physical features of the world. Draw attention to the frequent activity in young mountain systems and volcanic chains and also to the infrequent crustal activity in regions of plains and plateaus.

11–11
From continental drift to sea floor spreading
11–12
The plates of the earth's crust

These two sections can be discussed at the same time. Although there is much evidence to support sea floor spreading and plate tectonics, these two concepts must be treated open-endedly. The evidence is not conclusive that at one time a

super continent split and the pieces drifted apart. This is one of the most intensely studied topics in earth science research. You may be able to add newspaper reports of new findings to class discussions. A film is an especially valuable teaching tool for this section. Pages of explanation and description cannot show as clearly as a movie this exciting idea of the changing face of the world. One of the best films is *Continental Drift*, listed in the Supplementary Materials.

Students may be interested in seeing how well the data literally fits. Reproduce a world map for each of the students. Ask them to cut out the continents, including, where possible, the continental shelf of each, and try to fit the continents together to form one large land mass. The students may come up with many different ideas as to how "Pangea" or "Gondwanaland" might have looked. *The Confirmation of Continental Drift* listed in Supplementary Materials will give you some idea of possible results.

Focus the discussion of Section 11–11 on the findings of oceanographers in the mid-1960's. Point out that each finding resulted from extensive investigation of data collected by a variety of methods and instruments. As an example, data from the Earthquake Watch is valuable in making predictions about the areas of stress and volcanic activity. This discussion should lead naturally into Section 11–12.

Demonstration If you sprinkle sawdust on the surface of boiling water, you can observe the particles gathering where the currents sink. The sawdust represents the crust with the boiling water representing the convection cells within the earth. You might remind students during the discussion of Section 11–12 the importance of convection cells as part of the rock cycle.

Answers to thought and discussion

1. Why do earthquakes show areas of crustal activity? **Answer** When there is movement within the earth's crust, from volcanism, from crustal spreading, or from compression, the rocks must move. When they do, earthquakes result. A greater frequency of earthquakes in a region means the earth's crust is moving more.
2. How are volcanoes related to deep ocean trenches? **Answer** Trenches form where major plates of the earth's crust meet and create great compressional forces. Portions of the oceanic crust are carried beneath the continental crust. Volcanoes are the external result of this great crustal activity within the region of the trench.
3. What is the difference between mid-ocean ridges and geosynclinal mountains? **Answer** Mid-ocean ridges are formed where the earth's crust is spreading. They are features formed by tension. Volcanic activity is the result of magma pouring upward through tensional breaks in the crust. The ridges are, therefore, great chains of volcanic mountains.

   Geosynclinal mountains are sedimentary rocks that have been squeezed, folded, and faulted, and then were lifted up into a chain of folded mountains.
4. How does the stability of ocean basins and continents differ? **Answer** The action in the earth's crust is in the ocean basins and around their borders. Sea-floor spreading, motion between crustal blocks, and geosynclinal sequences are all ocean basin activities. Continental blocks, on the other hand, are the stable remnants of earlier crust formation. The core of a continent long ago experienced the active processes of major deposition, mountain building, and motion between major parts of the crust.
5. How do the ideas of continental drift and plate tectonics differ? **Answer** Continental drift is a relatively simple theory to explain why some land masses fit together like jigsaw puzzle pieces. It assumes the continents spread apart long ago. Plate tectonics is a much more extensive theory about movement in the earth's crust that may explain much more than just land shapes. It suggests that the crust is composed of six huge plates, or rigid areas, that moved apart from a center. Each plate is the top of a convection cell in the mantle. Spreading occurs at the rising parts of the cells, and compression at the sinking portions.

Discussion of unsolved problems

A really major theory such as plate tectonics rarely results from a step-by-step analysis of data, the way many smaller-scale discoveries are made. Instead, someone had a vision of the entire sys-

tem of convection cells. Then scientists began to look for evidence in previously collected data that the vision might be a possible answer to inconsistencies and unanswered earth science problems. Later, scientists designed new experiments to test the theory. When any new theory doesn't match the data, the theory is challenged, modified, patched, or expanded. Plate tectonics is at this stage of investigation now. Many details don't seem to fit.

Many questions could be answered if we knew more about the regions where the plates are colliding. Scientists trying to learn more about these areas, however, face a difficult problem: There is no direct way to study the oceanic crust that has been (according to the theory) pushed beneath continental rocks. Research using seismic methods to measure the thickness and structure of the hidden rocks is very complex and the information is difficult to interpret.

Answers to questions and problems

A

1. What evidence suggests that geosynclinal sediments have been deposited in shallow water? **Answer** Clues are found in the composition and structure of the sediments, as well as in the presence of mud cracks, ripple marks, and shallow-water fossils.
2. What features of the Gulf of Mexico Basin lead some scientists to believe that it is an active geosyncline? **Answer** It has a great accumulation of shallow-water sediments. Some volcanic debris has been found among the sediments. Offshore volcanic activity may be represented by such West Indian islands as Martinique.
3. What is the geosyncline theory? **Answer** Thick beds of sediments were generally laid down horizontally, with younger beds overlying older ones. These sediments were deposited in a shallow-water basin that sank to accommodate their weight. Later the beds were uplifted.
4. How do you know that rocks have been deformed? **Answer** In the case of sedimentary rocks, the most obvious evidence is the disruption of the original horizontal bedding. As deformation becomes intense, minerals also become altered and rock textures changed. The texture of a sedimentary rock such as a sandstone can change so drastically that it may not be easily recognized as a sedimentary material.
5. Describe the features of a folded mountain range. **Answer** The Appalachians can be taken as an example of a typical folded mountain range. They are a series of nearly parallel ridges and valleys. The rock, originally deposited in horizontal layers beneath a shallow sea, was deformed. Then it was lifted up to its present location.
6. What is a fault? Describe the various motions that may be associated with the formation of a fault. **Answer** A fault is a break or crack in a portion of the earth's crust that shows evidence of movement. The direction of movement may be vertical, horizontal, or a combination of the two. Most general geology books include sketches of basic types of fault movements.
7. Where on the continents are geosynclinal mountains generally located? Where in the oceans are island arcs generally located? **Answer** Geosynclinal mountains are generally located on the margins of continents. Island arcs are also on margins, near continental shelf areas.
8. Where is a mid-ocean ridge not a mid-ocean ridge? **Answer** Where it is not in the middle of the ocean — by the definition of mid-ocean ridges. Note that the ridge strays onto continents in places, as in the area of Baja California.
9. What are the different kinds of coral reefs and how do they form? **Answer** Coral reefs are the accumulated skeletons of animals that grow only in warm, shallow water surrounding an island or continent. If a reef extends out of the water, this means the sea is now lower than it was or the ocean floor has raised. If the reef is very thick, it means the opposite has happened.

B

1. In a geosynclinal basin, where does most of the rock deformation take place? Describe the conditions and the changes caused by these conditions. **Answer** Apparently rock deformation takes place near the axis (or center) of a geosynclinal basin. Deformation

usually is considered to be caused by compressional forces. The materials are warped, folded, faulted, and uplifted by pressure from both sides.

2. Where does the energy that causes earthquakes come from? **Answer** It is energy previously stored in rocks as potential energy similar to that stored in a twisted or squeezed spring. This stored energy must also have had some origin. (Chapter 13 discusses some of the possible sources.)
3. What evidence indicates that island arcs may be a middle stage in the formation of geosynclinal mountains? What evidence rules against this idea? **Answer** While the Text gives little specific evidence that island arcs are related to middle stages of a geosyncline, virtually all ancient geosynclinal mountain systems include volcanic rocks. From this and a study of present basins that appear to be geosynclinal, volcanism is presumably associated with geosynclinal mountain building. However, island arcs may actually represent the early stage in the formation of geosynclinal mountains. The arcs may be the source of part of the sediment that accumulates in the geosyncline.
4. What should happen to the crust of the earth where volcanic islands are growing? **Answer** The crust should be sinking under the load of volcanic material. The crust also may be collapsing as volcanic material is removed from below.
5. Give a possible explanation for the development of mid-ocean ridges and trenches. **Answer** Some scientists think that mid-ocean ridges and trenches occur where two adjacent convectional currents in the mantle rise and diverge. Thus, the sides of the ocean basin are thought to be sliding away from one another and toward adjacent continents. These rising convectional currents produce features such as mountains.

   Do not restrict discussion to the possibilities that have been mentioned or indicated in the Text. This is an excellent opportunity to evaluate the students' ability to visualize general earth processes and to think in a very large scale.
6. Why are the mid-ocean ridges not believed to be the result of compression? **Answer** These ridges do not show features commonly associated with compression (folds, thrusting, and so forth). Instead, their features are associated with tension in the earth's crust. Scientists hypothesize that whatever is compressing the crust in geosynclinal areas could be pulling it apart at sites in between. These sites might be the mid-ocean ridges.
7. How did the tops of seamounts become eroded if their present level is far below the lowest possible level of the oceans? **Answer** The earth's crust may have subsided under the seamount, dropping it far below sea level.
8. How is it possible to find corals at a depth of 1400 meters when coral does not form below a depth of 80 meters? **Answer** The sea level has risen or the land level has lowered, or both. This is the same idea as that involved in the answer to question 7.
9. Describe the difference between materials in the continental and oceanic crusts. How do we know about this difference? **Answer** The continental crust is essentially granitic and richer in silica, potassium, and aluminum than the oceanic crust, which is basaltic and richer in iron and magnesium. This difference is known from chemical analysis, petrographic analysis, and seismic data.
10. How do the water cycle and the rock cycle work together? **Answer** The water cycle transports solid earth material from areas of high potential energy to lower elevations. This shifting of solid material is part of the rock cycle, which is driven by the runoff portion of the water cycle.

C

1. As sediments move from high areas into geosynclinal basins, they lose potential energy. So does the water that moves them. What is the source of the potential energy of the sediments and the water? **Answer** The source of potential energy of the sediments could be thermal energy derived from radioactivity. Radioactivity is thought to be the source of energy that lifts up geosynclines as well. The source of potential energy of the water is the sun.
2. Under what conditions would the remains of animals that had lived on land be found in sea floor deposits? **Answer** The remains might

have been washed out to sea, or the sea might have encroached on the land where the animals lived and died.

3. Besides the weight of the sediments, what other force probably aids in the subsidence of geosynclines? **Answer** According to the theory of plate tectonics, the forces of compression at the boundaries of colliding plates in the earth's crust would contribute to the sinking of the geosynclinal basin.
4. What finally causes the uplift of these deep geosynclinal rocks? **Answer** The weight of the sediments and the forces of compression at the boundaries of colliding plates force the crust to subside during early stages of the geosyncline. When the accumulated sediments become too thick, their downward pressure is not equal to the reaction of the mantle pushing back. The basin, squeezed from all directions but one, is forced upward like toothpaste from a tube.
5. Describe the processes that could someday make the East Indies and Japan a part of the Asian mainland. **Answer** The filling of the Japan Sea by material from the adjacent continent and the islands, and possibly eventual uplift.

Supplementary Materials

Reference books

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12. Rocks Within Mountains

Chapter Objectives

After completing this chapter, students should be able to:

1. Describe what happens when a pluton forms.
2. Distinguish between plutonic and volcanic rocks in terms of occurrence, mineral and chemical composition, and texture.
3. Discuss how temperature, pressure, and mineral solutions affect rocks at the surface and below.
4. Analyze the intensity of metamorphism from a rock's texture and mineral content.
5. Discuss various theories for the origin of granitic rocks.
6. Explain the relation of plutonic rocks to the occurrence of regional metamorphism.
7. Trace the changes in quartz and feldspar grains in a granitic rock as the rock undergoes these processes: weathering, erosion, deposition, folding, metamorphism, and then melting and recrystallization as a granitic rock.

Teaching the Chapter

This chapter introduces plutonic, metamorphic, and volcanic rocks, the rocks that are not sedimentary in origin. The discussion of the formation of these rocks completes the Text's account of how mountains form.

In several investigations in this chapter students examine the properties of rocks. Then they suggest conditions under which the rocks must have formed. Students also interpret a geologic map to discover the relative ages of the rocks listed in the map's key.

Suggested time required

It should take five to seven class periods to discuss the topics and complete the investigations in this chapter.

Section Notes

12–1
A young mountain range

The high mountains of central Montana are typical of a mountain range developed in a mobile belt of the crust. Much of this chapter will focus on examples from such mountains.

In the Philipsburg area a thick sequence of sedimentary rocks accumulated over a total time span of perhaps a billion years. These rocks were intensely folded and faulted about 80 million years ago. The complex relationships of these rocks are shown on the geologic map in Figure 12–2 and the geologic cross section of the same area in Figure 12–3. Investigation 12–2 acquaints students with the variety and arrangement of rocks in the Philipsburg area.

12–2
Using a geologic map to study rocks

TIME REQUIREMENTS

Pre-lab	10 minutes
Lab	15 minutes
Post-lab	10–15 minutes

MATERIALS

The following materials will be needed by each class:

Modeling clay, several colors (optional)
Geologic maps of other areas (optional)

Pre-lab discussion

Begin the discussion of the investigation by introducing students to the features of a geologic map. Point out how to read the scale and legend and what the different colors represent. Students should understand that the different colors represent rocks of different ages. The legend in the map indicates the order in which these rocks formed.

You can help students learn to read geologic maps by showing the class the geologic maps of several different areas. Let students discuss the differences and similarities among the maps.

Notes on procedure

Keep this investigation open-ended and allow students to reach their own answers to the questions. One way to structure the discussion is to let students compare their answers in groups of five. Ask the groups to arrive at a consensus answer for each question. Then, with the entire class, let the groups compare answers. Try to arrive at a consensus answer for each question.

Many teachers find it useful to have modeling clay available. A student or group may want to illustrate a particular point by constructing a model of a geologic cross section.

Range of results

Many students may be confused when they first look at the map. It may appear to be a jumble of symbols and colors. As discussion progresses, however, students should realize that to interpret the map, they have to distinguish only a few items. Once students have established that there are a large number of sedimentary rocks (faulted and folded), several large plutons, and a legend that explains the order in which the sedimentary rocks were deposited, the questions usually present few problems.

Don't overdo the map study in this lab. Students will work with maps in more detail in Chapter 14. At this point students should concentrate their attention on the relative ages of the rocks in the Philipsburg area.

Post-lab discussion

If students can read a geologic map well enough to answer the questions, they should be able to determine the relative age of the plutons.

Answers to questions

1. If rocks are displaced by faults, might faults displace faults? **Answer** Yes. An example on the map is located just north of Philipsburg. Another is just south of the large pluton P-3.
2. Look at the fault lines north of Philipsburg. Some run almost north-south, others more nearly east-west. Which set do you think is younger? **Answer** The east-west fault lines are younger, since they have displaced the north-south fault lines.
3. Some of the faults shown shift the boundary lines between various sedimentary rock layers. Does this mean that the faults are older or younger than the rocks? **Answer** Since the rocks must exist before faults can occur in them, the faults are younger than the rocks in which they occur.
4. Look at the somewhat round area of rock labeled P-3 just east of Philipsburg. Does this rock cut across or parallel the units of sedimentary rock? **Answer** It cuts across the sedimentary layers, just like the faults do.
5. Would you conclude that this rock is older or younger than the sedimentary rocks it touches at the surface? **Answer** It must be younger.
6. Would you conclude that P-3 is older or younger than the faults? **Answer** Since all faults are cut by the plutons P-3 and P-8, the faults must have existed first. The plutons, then, are younger.
7. Notice that P-3 is not shown in the legend of the map. Where would you put it in the legend? **Answer** Evidence indicates that the plutons are the youngest rock on the map. They are also younger than the deformation of the sedimentary rocks.

Suggested additional activities

Later in the course, during Chapters 16, 17, and 18, you may want to return to this geologic map. By that point, students will have discussed the Geologic Time Scale, superposition, crustal processes, and interpretation of the rock record. With this added background they should be able to reconstruct the sequence of geologic events in the Philipsburg area with little difficulty.

If you wish to use the geologic ages for the rocks when you do this, A1 and A2 are Precambrian, Є3 and Є4 are Cambrian, S-D5 is Silurian and Devonian combined, C6 and C7 are Carboniferous (including Mississippian, Pennsylvanian, and Permian), J8 is Jurassic, and K9 is Cretaceous. The plutons, younger than these other rocks, are early Cenozoic in age. You might ask students what geologic periods from Cambrian to Cretaceous are not represented by rocks in the area of the map? How do you account for their absence? Rocks may not have been deposited during those times, or they may have eroded away before the next layer was deposited.

12–3 Plutons

The most conspicuous rock masses on the geologic map are the irregular areas such as the one labeled P-3 just east of Philipsburg. The pluton east of Philipsburg is typical of the many smaller masses of granitic rocks in young mountain ranges. The emphasis in this section is directed toward understanding how these rock bodies form and where they occur.

For your convenience, the important facts about plutons can be summarized as follows. (Students are not intended to memorize the list.)

1. Plutons are large masses of rock that develop within a belt of deformed sedimentary rocks.
2. Plutons form after most of the deformation of the sedimentary rock has occurred.
3. Plutons appear to replace the older rocks rather than push them aside or otherwise displace them.
4. The boundary between the pluton and the older rocks is steeply inclined outward. In other words, the pluton enlarges downward. (See Figure 12–3).
5. Plutons typically are elongated parallel to the trend of the mountain range in which they occur.
6. Large plutons are made up of several distinct masses of rock. Each mass is essentially uniform in composition and texture.
7. Plutons range in composition from basaltic to granitic. (See Figure 12–13.)
8. By far the most abundant rocks in plutons are the quartz-bearing granitic rocks. These are perhaps twenty times as abundant as all other plutonic rocks combined.
9. Plutons are, by tradition, considered to be intrusive igneous rocks formed from material that was hot and fluid. Controversy continues, however, about the origin of the hot, fluid material (magma) and the processes that place it within the deformed mountain belt.

12–4 Investigating plutonic rocks

Advance preparation

Arrange the plutonic rocks in small boxes or beakers. Students should be able to begin working immediately after the introductory discussions.

Time requirements

Pre-lab	5 minutes
Lab	15–20 minutes
Post-lab	5–10 minutes

Materials

The following materials will be needed by each group of two students:

- Magnifier from Teacher's Kit
- Teasing needle (optional)
- Rock specimens from the Earth Materials Kit:
  - Pink granite
  - Gray granite
  - Diorite
  - Gabbro
  - Granodiorite (optional)
  - Syenite (optional)
  - Peridotite (optional)
  - Dunite (optional)
- Stereomicroscope (optional)

Special notes

The objective of this investigation is that students be able to distinguish certain physical properties of plutonic rocks and discuss what caused these properties. It is of minor importance that students know the actual names of the rocks. The three rock investigations in this chapter are *not* intended to be used as vehicles for rock name memorization. It is far more important that students practice the thinking processes employed by geologists when they group or classify rocks.

Pre-lab discussion

You can use Section 12–3 as an introduction to plutonic rocks. After you have discussed that section, ask students which properties they think might be most useful in telling one plutonic rock from another. Be sure you don't give away the right answers.

Notes on procedure

Let students use the questions in the Text as a guide for the investigation. Remind students to use the hand magnifiers or stereomicroscopes, if they are available. Don't insist that students use the entire time allotted for the lab. You can begin the post-lab discussion whenever students seem ready to go on to something else.

Range of results

Most students will be able to separate the rocks on the basis of color. Their grouping of "dark-colored rocks" should include only black and dark gray. Students will have more trouble estimating the percentages of minerals in the rocks. You should expect little precision, although some students will be able to identify granite and gabbro.

Post-lab discussion

Use a transparency of Figure 12–13 to demonstrate how to use the diagram. You might take for an example one of the plutonic rocks that is not identified by name in the Text. Diorite or syenite would be good to use. Let the students point out granite and gabbro using their own observations as evidence.

There is no need to discuss igneous rocks extensively at this time. Students will return to that topic later in the chapter.

Answers to questions

1. How many specimens do you have in each group? **Answer** This depends, of course, on which rocks the students used. In one group students might expect to find pink granite and syenite; in the other, gabbro, gray granite and diorite. Granodiorite should be in the light-colored group. In any case, variation of the qualities of the specimens may make identification difficult.
2. Try to estimate the relative percentages of feldspar and quartz in each of the rocks. **Answer** Granite and granodiorite will contain quartz. Quartz should be missing in syenite and the other specimens. The light-colored group will have significant percentages of pink (orthoclase) feldspar; the dark-colored group will have large percentages of gray (plagioclase) feldspar.
3. Try to estimate the percentage of black grains. **Answer** The occurrence of the dark minerals could range from 10 to 20 per cent.
4. Can you easily distinguish the feldspar from the black minerals? **Answer** This will depend upon the students' samples. White or gray feldspar, however, is not as easy to pick out as pink feldspar. Feldspar is hardest to distinguish in some of the dark-colored rocks.
5. Try to estimate the percentages of feldspar and black minerals. **Answer** This is easiest in the light-colored rocks. Encourage students to use Figure 12–13 as they observe the rocks. Can students determine from the figure the percentage of feldspar for gabbro, a "basaltic" rock? Can they confirm this in a specimen? Diorite is about midway between the shaded areas of the figure. Granodiorite is at the right edge of the granitic shaded area. Syenite is left of the granitic shaded area (no quartz).

Answers to thought and discussion

1. Estimate the area of the pluton just east of Philipsburg. If it extends downward to a depth of five kilometers, what is the volume? **Answer** A reasonable estimate can be calculated with the aid of a grid of squares two kilometers on a side. Each square contains four square kilometers. Lay the grid over the map and count the number of complete squares within the boundary of the pluton. Then estimate how much of each partial square is filled. Most students will estimate a total area a little over 100 square kilometers. Multiply area by thickness to get volume.
   about $100\ km^2 \times 5\ km =$ about $500\ km^3$
2. Assume the molten mass surrounded by cooler sedimentary rocks had a temperature of 800°C. How long would you estimate it would take the pluton to cool to 100°C? Would the heat escape from the pluton mainly by radiation, convection, or conduction? **Answer** The heat must escape mainly by conduction

through the surrounding rock. Rocks are very poor conductors of heat, so it would take a long time to cool the mass to 100°C. Reasonable estimates of the time required to cool this mass to a depth of five kilometers should vary from one to perhaps three million years. Students might be asked to review their knowledge of the use of rocks and rock materials for insulation.

3. Would you suspect that the slow cooling of a pluton affects the texture (grain size) of the rock which forms? Did some of the plutonic rocks you examined differ from others in average grain size? How would you explain the differences? **Answer** The rate of cooling is perhaps the most important factor in producing differences in grain size in plutonic rocks. The rate of cooling may be influenced by the depth of the rock below the surface or by the amount of water in the magma.
4. Can you suggest a reason for the much greater abundance of granitic rocks compared to basaltic rocks in plutons? **Answer** At this point in the chapter the most reasonable hypothesis is that large volumes of the upper crust are somehow melted and crystallized to form new rock. The question is raised here to enable students to decide that they know too little to reach a consensus conclusion. If some students have read ahead a little they may be able to suggest a more sophisticated hypothesis.

12–5
Metamorphic rocks
12–6
Metamorphism varies with rock environments.

You might begin by asking students to name two sources of the heat that causes metamorphism. The temperature at any point within a mountain range will be influenced by depth below the surface, and by the presence of plutons. Students may suggest that pressure also can come from two sources. Pressure within a mountain range depends on depth and also on the presence or absence of the compressive forces that produce the folding and faulting.

You may need to review where the water involved in metamorphism comes from. If there is free water filling the spaces between the grains of the rocks, it will be a dilute solution of the mineral matter within the rock. At higher temperatures the water can dissolve minerals more easily. The solution that results will be more concentrated and thus more effective in changing the rock.

Another source of water for metamorphism is the water included in the mineral's atomic structure. Some common rock minerals such as the clay minerals, micas, and amphiboles contain water in their atomic structure. This water may be liberated at high temperature. Then it adds to the amount of free water available for metamorphism.

In most sandstones there are voids between the sand grains. (See Figure 12–5.) These voids usually are filled with water, often seawater trapped in the rock at the time of deposition. As temperature and pressure increase the water begins to dissolve the sand grains at the points where they contact each other. Quartz is very insoluble, however, even in hot seawater. The material dissolved from one point will be deposited somewhere else on the surface of the grain. In time the holes will be filled with quartz, the water will be driven out, and the rock will be denser than it was before.

If other materials such as the fossil shells in Figure 12–6 are present in the rock new minerals may form. In this instance the calcium compound of the shells reacts with dissolved silica to form calcium silicate, a typical metamorphic mineral.

Students may be interested in knowing that metamorphism is reversible. Rocks metamorphosed under the most intense conditions are usually at great depth. When these rocks are brought toward the surface by erosion the temperature and pressure are reduced. The minerals in the rock may adjust to the new environment by further changes. The changes produce a greater variety of metamorphic rocks. Students may confuse this reversed metamorphism with weathering. It is not the same thing at all. The rock is not broken down as in weathering. The changes are inside the rock.

12–7
Investigating metamorphic rocks

Advanced preparation

Arrange the rocks in sets and place them in small boxes or beakers, ready for students to use.

Time requirements

Pre-lab	5 minutes
Lab	10 minutes
Post-lab	10 minutes

Materials

The following materials will be needed by each group of two students:

- Magnifier from Teacher's Kit
- Rock samples from the Earth Materials Kit:
  - Marble and limestone
  - Quartzite and sandstone
  - Slate and shale
  - Mica schist
  - Granite gneiss and granite
  - Phyllite
- Mica specimens (optional)
- Stereomicroscope (optional)

Pre-lab discussion

Use the transparency of Figure 12–8 you made in Investigation 12–4 when you begin discussing this investigation. Many students already may know some of the rock pairs, but most will not. Ask students to look for evidence of deformation *within* the rock.

Notes on procedures

This investigation will proceed very rapidly once students identify the metamorphic rocks that resulted from each non-deformed sample. The relationships between the rocks, however, are not always obvious. As you circulate around the room encourage students to look for similar properties and colors. Students need not be able to identify the metamorphic rocks by name.

Post-lab discussion

Ask students if they observed any evidence of the origin of the rocks. One of the most frequent observations students make is that the banding of the gneiss may be evidence of deformative forces. What properties of a rock would remain unchanged through the metamorphic process? If thin sections of metamorphic rocks are available (photographs of thin sections will also work) ask the class what evidence they can find to help answer the questions.

Answers to questions

1. How do these rocks differ in texture and mineral composition from the sedimentary rocks? **Answer** In quartzite, marble, and granite gneiss, texture and mineral composition remain the same. Most other metamorphic rocks, especially schists, show coarser texture and obvious changes in mineral composition. Metamorphic rocks typically show laminations as their most obvious characteristic.
2. If you have more than one specimen of any of the metamorphic rocks, how do they differ from each other? How would you explain these differences? **Answer** Since the degree of metamorphism and the properties of the parent material may differ, the properties of metamorphic rocks rarely are uniform from sample to sample.
3. Plutonic rocks may also be changed by metamorphism. Do you have any metamorphic rocks you think may have originally been granite? If so, what evidence indicates this origin? **Answer** Most students will identify gneiss as the metamorphosed granite. The identifying properties are its similar color and mineral composition. The banding of the gneiss indicates the deformation within the rock.

12–8
The origin of granite

This section presents science as a process of finding out, not a set of answers. As with many questions about the origin of things, the answers are not known. From material in earlier sections it seems obvious that at least some granitic rocks may be produced by metamorphism of very high intensity. Field evidence supports this origin for at least some granites. The controversy is over how much granite is metamorphic and how much is igneous in origin. An acceptable answer has not been reached.

Answers to thought and discussion

1. Find out how ordinary bricks are made. In what ways does the manufacture of bricks resemble metamorphism? **Answer** Bricks are made by molding stiff clay into the desired shapes and sizes, then heating them to high temperatures in an oven. The temperature causes a reaction between the minerals in the clay and produces a hard, durable, rocklike

material. This process is similar to metamorphism. In particular it resembles the changes in shales near a pluton.

2. At one time weathering was considered to be a special kind of metamorphism. Why do you suppose this was done? Why is it no longer done? **Answer** It is just a matter of how you use the words. "Metamorph" means "change in form," and certainly weathering is a process that changes rocks to new forms. The term metamorphism is now restricted to those changes occurring at high temperatures and pressures within the crust. Weathering occurs in the surface environment.
3. Do your observations suggest a gradual change in texture in the metamorphic series from shale to gneiss? How would you explain the presence or absence of such change? **Answer** In general, there should be an obvious gradation from fine to coarse texture in this series. The change reflects the higher temperature and pressure in the environment where gneiss forms.
4. A schist formed at great depth near a pluton may be brought to the surface very slowly by erosion. Such rocks commonly show changes in mineral composition and texture. Would you consider these changes to be metamorphism? **Answer** The answer to this question was discussed in the notes for Section 12–5.
5. The discussion of metamorphism emphasized temperature, pressure, and solutions as important factors. Can you suggest another factor which should be included? **Answer** Two additional factors should be obvious: the nature of the original rock and the duration of the metamorphic process.

12–9
Rocks upon mountains

Volcanic rocks, whether they occur in volcanoes, on the eroded mountains, or in lava plateaus, have an uncomplicated history. There can be no doubt that these are igneous rocks. They crystallized from molten material which poured out on the surface. Unlike many geologic processes, this process can be examined in great detail at any active volcano.

Volcanic rocks are basaltic in mineral and chemical composition. The contrast in mineral composition between granitic and basaltic rocks is clearly shown in Figure 12–13. Molten material of this composition cannot be the result of melting any possible combination of common sedimentary, plutonic, or metamorphic rocks. The most likely source of basaltic magma is the upper mantle, just beneath the earth's crust.

12–10
Investigating volcanic rocks

Advanced preparation

Arrange the rock samples in small boxes or beakers so students may begin work immediately after the short pre-lab discussion.

Time requirements

Pre-lab	5 minutes
Lab	10 minutes
Post-lab	10 minutes

Materials

The following materials will be needed by each group of two students:

- Magnifier from Teacher's Kit
- Stereomicroscope (optional)
- Rock samples from the Earth Materials Kit:
  - Felsite (non-porphyritic)
  - Basalt (dense)
  - Basalt (vesicular-scoria)
  - Rhyolite (porphyritic)
  - Andesite
  - Obsidian
  - Pumice
  - Salol (optional)

Pre-lab discussion

Review briefly the results of Investigation 12–4 on plutonic rocks. Point out to students that the objective of this investigation is to identify the properties of igneous rocks that differ as a result of their plutonic or volcanic origin. You might ask students to predict what those properties will be. (Accept all predictions—students will discover for themselves in the investigation whether or not they are correct.)

Notes on procedure

Students use the questions as a guide to the procedure they are to follow. If you have not discussed the igneous rock composition diagram in Figure 12–13, it may need some explanation.

A transparency of the diagram will be very useful. Students will use the diagram to identify some of the rocks.

Post-lab discussion

As you begin discussing the answers to the questions, pour melted salol into several large watch glasses. Place at least one of the watch glasses on crushed ice. Let the others cool at room temperature. By the end of the discussion the "iced" salol should have solidified, and the other solutions should contain several large crystals. Ask students what was the effect of cooling time on grain size. A major difference between plutonic and volcanic rocks should be obvious.

Answers to questions

1. What is the main difference between these rocks and plutonic rocks? **Answer** Most students will identify grain size as the significant difference, although some may select color or density. Volcanic rocks have small grains compared to plutonic rocks. (Obsidian, in fact, is not crystalline in structure and has no grains at all.)
2. Assuming that these rocks have about the same chemical composition as plutonic rocks, how would you explain the difference? **Answer** Since volcanic rocks cool and solidify at or near the surface, their cooling time is much shorter than that of plutonic rocks. Grain size is a result of cooling rates: a slow cooling rate produces large grains; a rapid rate produces small grains or no grains at all.
3. Which group would you consider to be granitic and which basaltic in composition? **Answer** Generally, the lighter colored igneous rocks are granitic and the darker samples are basaltic.
4. If you have a piece of obsidian, in which color group did you place it? **Answer** Students almost always place the obsidian with the basaltic rocks.
5. Obsidian is actually granitic. Can you suggest why it is black? **Answer** Only large pieces are black. A thin chip of obsidian is light gray or colorless. A large piece appears black because light is absorbed by the obsidian and not reflected back to your eyes. This property is not unique to obsidian. Very thin slices of pyroxene (darkest of the black silicates) and basalt are colorless, too.
6. What are the main mineral differences between granitic and basaltic rocks? **Answer** Both kinds of rocks are composed of high percentages of silicate minerals, but the lower density granitic rocks don't have much iron and magnesium. The higher density basaltic rocks are usually rich in these two elements. Granitic rocks usually are rich in potassium and sodium aluminum silicates and quartz.

Answers to thought and discussion

1. Nearly all obsidian is geologically young. There are no obsidians among volcanic rocks more than a few million years old. Try to think of at least two possible reasons for this situation. **Answer** One possible explanation for the absence of old obsidians is that none formed until recently. A second possibility is that they were destroyed before they could be protected by burial. All volcanic rocks form at the surface and are immediately weathered and eroded. Glassy rocks like obsidian can be expected to not resist erosion very well.

   A third, and the true explanation, is that obsidians change in time to something else. Among older volcanic rocks there are some with the chemical composition of obsidian, consisting entirely of very fine grains of quartz and feldspar. Under the microscope these rocks show evidence of the curved contraction cracks typical of glassy rocks. These must be glassy rocks which have completely crystallized. (Obsidian, like ordinary window glass, is not a true solid. It is a supercooled liquid with an undeveloped crystal structure.) Ordinary window glass more than a few centuries old shows evidence of crystallization.
2. How could you distinguish between a basaltic lava flow covered by a layer of younger sedimentary rock and a layer of basaltic rock injected between two layers of older sedimentary rock? **Answer** The lava flow would bake only the rock below it. The upper surface of the flow probably would show some evidence of weathering. Fragments of it may occur in the overlying layer of rock. The injected igneous rock would bake (contact metamorphism) the rocks above and below it.
3. Considering the great volumes of granitic rocks in plutons why are rocks of this composition so rare among the volcanic rocks? **Answer**

Volcanic rocks of granitic composition are very viscous. They tend to pile up in thick masses rather than spread out over large areas the way basaltic flows do. This high viscosity would slow down the rise of granitic magmas toward the surface. Granitic magmas have a lower temperature than basaltic magmas, so they would tend to crystallize as they rise to the upper levels of the crust.

Their rise also would be slowed as water and other volatiles escape through the surrounding sedimentary rocks. Granitic rocks formed by extreme metamorphism probably never were really fluid. They would not tend to rise to the surface. Some granitic rocks may result from the melting of older sedimentary rocks where the plutons occur. This could happen only at great depths where temperatures high enough to melt the rock could occur.

Discussion of unsolved problems

The dynamics of the mobile belts of the continents from which mountain ranges arise represent a whole series of problems. It is an area of investigation characterized by almost as many postulates and hypotheses as there are investigators. No hypothesis is well-enough accepted even to be called a theory. Most, if not all references are biased in favor of one or another hypothesis. You might explain to your students that books on science do not contain only accepted fact.

The more controversial issues touched in this chapter may be broadly summarized as follows:

1. What is the nature and cause of the subsidence of the earth's crust in geosynclines? (Of course Chapter 11 presents one well-accepted explanation.)
2. How do the sedimentary rocks in a geosyncline deform and what is the source of the forces which produce the deformation?
3. What is the origin of the great plutonic masses of granitic rocks in the midst of developing mountain ranges? (This is called the "granite problem.")
4. What causes regional metamorphism and how does it work? What is the relative importance of temperature and pressure in the development of metamorphic rocks? Is there a simple cause-and-effect relation between metamorphism and the occurrence of plutonic rocks?
5. What is the source of basaltic magma?
6. Why is volcanism a late event in the development of a mountain range?

Answers to questions and problems

A

1. Why are environmental conditions within the crust different from those on the surface of the earth? **Answer** Both temperature and pressure are greater inside the earth. There is also no chance for free water and atmospheric gases—two important influences on surface rocks—to affect rocks within the crust.
2. Why are some igneous rocks fine-grained and some coarse-grained? **Answer** The conditions under which igneous rocks cool probably are the main factors controlling grain size. Slow cooling is likely to produce coarser-grained rocks. Rapid cooling is likely to form finer-grained rocks. Slow cooling usually occurs when the rock is inside the earth. Rocks cool more quickly at or near the surface.
3. What is likely to happen to sandy clay sediment buried for a long time at a depth of 20 kilometers? How might such rock be changed into granite? **Answer** At a depth of 20 kilometers clay is under high pressures. It would be warmed slowly by the flow of heat from the deep crust and mantle. It would become progressively more metamorphosed. If this clay were heated still more, it might reach the conditions of intense metamorphism. It probably would become granite only if additional heat energy were supplied, perhaps by convection currents in the mantle or from radioactive decay of elements in the sediments. If the temperature rose beyond about 620°C, the sediment would melt (at least partially) to form granitic magma. On eventual cooling it would form granite.

B

1. Estimate the difference between the approximate temperature when rocks begin to melt and the average crustal temperature at a depth of 20 kilometers. Assume the rock composition is granitic. (Refer to Figures 12–4

and 12–9.) What is the significance of this temperature difference? **Answer** Figures 12–4 and 12–9 show an average crustal temperature of about 400°C at 20 kilometers below the surface. Granite at that depth melts at above 700°C. This temperature difference indicates that even if the crust at a depth of 20 kilometers is composed of granitic rock, it would be solid.

2. Are all granites igneous in origin? In what other way do granites form? **Answer** No. Granite may form by extreme metamorphism under mountain systems at temperatures that are just below its melting temperatures.

C

1. By melting granite in an open container, early investigators tried to discover the lowest temperature at which a magma of this composition could exist. How meaningful were such experiments? What other factors should be controlled to make such experiments more meaningful? **Answer** Water and other fluids can be retained at high temperatures under high pressures in a confined space. This greatly influences the melting behavior of rock. Water confined under pressure reduces the temperature at which rock begins to melt. Since water is a widespread constituent of rocks at depth, melting rock in an open container is, in effect melting it dry. This method cannot reveal the lowest temperature at which magma can exist. This temperature can be found only by heating rock with water under pressure.

   A further complication is that dry melts are so viscous that it is difficult to tell when melting has occurred. As a result, most early investigators thought that rock melted at a higher temperature than it does.

2. Certain ancient rocks exposed in mountains are called volcanic rocks. Since their formation was not seen, how do you think it can be determined that they are volcanic? **Answer** Ancient volcanic rocks are recognized by comparing them with modern volcanic rocks. Scientists observe that the mineral composition, texture, and occurrence are similar to those of modern volcanic rocks whose origin can be observed.

3. Suppose that the earth had no atmosphere. Would this have any effect on the amounts and kinds of rocks that compose the crust? **Answer** If the earth had no atmosphere, it would have no hydrosphere. It would be impossible for any significant amount of sediment to form. There would be no metamorphosed equivalents of such sediments. Much less mountain-building activity as we know it would occur because of the lack of sediment accumulating in geosynclines. There would be mainly volcanic and plutonic igneous rocks and perhaps some of their metamorphosed equivalents.

4. What evidence indicates that plutonic and volcanic rocks are not two parts of a single event in a mobile belt? **Answer** Volcanic rocks form at various times during the whole process. When they occur as lava flows in the sedimentary rocks of the geosyncline, these volcanic rocks are older than the plutonic rocks. The major accumulation of volcanic rocks, however, is clearly younger than the plutonic rocks. Plutonic and volcanic rocks are distinctly different in composition and time of origin.

Supplementary Materials

Reference books

Bayley, Brian. *Introduction to Petrology.* Prentice-Hall, Inc., Englewood Cliffs, N.J., 1969. A college level text, well-written and illustrated. It should be helpful to students who wish to pursue ideas further.

Mather, Kirtley F. *The Earth Beneath Us.* Random House, New York, 1964. An overview of geology for the general reader. It is profusely and beautifully illustrated.

Matthews, William H., III. *Invitation to Geology: The Earth Through Time and Space.* The Natural History Press, Doubleday & Company, Inc., New York, 1971.

Milne, L. S. and Milne, M. *The Mountains.* Time-Life, Inc., New York, 1962.

Romey, William D. *Field Guide to Plutonic and Metamorphic Rocks.* ESCP Pamphlet Series, Houghton Mifflin Company, Boston, 1971. A

succinct summary of the nature and origin of plutonic and metamorphic rocks. It also provides a general guide to the recognition and study of these rocks in the field.

Shelton, John S. *Geology Illustrated.* W. H. Freeman and Co., San Francisco, 1966. Simply written text with an unusually large number of excellent illustrations.

Wyllie, P. J. *The Dynamic Earth.* John Wiley and Sons, Inc., New York, 1971. A recent summary of the dynamics of the crust and the interior of the earth. The presentation is historical with brief reviews of the contending hypotheses on most issues. The author successfully distinguishes between facts and interpretations and avoids dogmatic positions. His presentation of the emerging facts and hypotheses regarding sea floor spreading and plate tectonics should be useful to teachers and advanced secondary science students.

FILMS

How Solid Is Rock? 20 minutes, color. American Geological Institute-Encyclopaedia Britannica Educational Corp.

Investigating Rocks. Filmstrip set. AGI-EBEC. Titles of interest include 4-"Volcanic Rocks," 5-"Plutonic Rocks," 6-"Metamorphic Rocks," 7-"Recognizing Rock-Making Minerals," and 8-"Comparing Rocks."

Rocks and Minerals. 11 minutes, color. Film Associates of California.

Rocks That Originate Underground. 23 minutes, color. AGI-EBEC.

Why Do We Still Have Mountains? 20 minutes, color. AGI-EBEC.

13. The Driving Force of the Rock Cycle

Chapter Objectives

After completing the chapter, students should be able to:

1. Give several reasons why scientists study the interior of the earth.
2. Explain how seismic data is used to determine the earth's internal structure.
3. Determine earthquake epicenter locations from the differences between P and S wave arrival times.
4. Discuss the source of most of the earth's heat.
5. Discuss the importance of heat flow and magnetic stripes in rocks to the theory of plate tectonics.

Teaching the Chapter

Students now shift their focus from the processes that mold the surface of the earth. In this chapter they concentrate on the earth's interior and begin by experimenting with a rubber sphere. Although they cannot open the sphere or see inside it, students are asked to describe its internal structure. This is analogous to ways scientists study the inside of the earth.

Students investigate how waves travel through the materials of the earth. Then they locate the earthquake's epicenter using observations of the different travel times of the seismic waves it produced.

The theory of plate tectonics developed in earlier chapters is used to explain the patterns of heat flow and magnetism in rocks.

Suggested time required

It should take six to eight periods to discuss the topics and complete the investigations in this chapter.

Section Notes

13–1
Investigating the inside of a sphere

ADVANCE PREPARATION

Familiarize yourself with experiments that imply differences between the spheres.

MATERIALS

The following materials will be needed by each group of two students:

Two spheres from Sphere Dynamics Kit. They are of identical size and mass, but one has its mass uniformly distributed. The other's mass is concentrated near the surface.

TIME REQUIREMENTS

Pre-lab	5 minutes
Lab	20 minutes
Post-lab	20 minutes

PRE-LAB DISCUSSION

In this investigation students experiment with two spheres to discover differences in their interiors. Students must rely on differences in the spheres' behavior in order to do this. This investigation should provide insight into how scientists investigate the interior of the earth.

Ask students how they would investigate and describe something they cannot see. How are scientists able to talk about the inside of the earth, or an atom, when they have seen neither? When direct evidence is not available scientists must make inferences from indirect evidence.

NOTES ON PROCEDURE

Leave students entirely on their own. Suggesting solutions to problems students encounter can inhibit their inventiveness.

Range of results

The spheres may not be the same color. Most students will notice this difference right away. If the spheres are not made of the same material, students may notice differences in surface appearance or texture. If one sphere bounces higher than the other, students may attribute this to a difference in material. The spheres may feel different when squeezed. Some students may notice a difference just from rolling the spheres around in their hands.

The most important difference between the spheres is the mass distribution. One sphere has its mass concentrated toward the surface. The other sphere has a uniform mass distribution.

There are several ways students might discover this difference. Spinning the spheres on a level table or in water is one way. The sphere with its mass near the surface will be harder to start spinning and harder to stop. One method to eliminate the inequalities inherent in hand-spinning is to roll both spheres down a slight incline onto the floor. The ball with the uniform mass distribution rolls more quickly down the incline. Yet, when it reaches the floor it slows down faster, so that the other sphere catches up and passes it.

Post-lab discussion

A spirited discussion should arise during the post-lab. Some differences will be discovered by almost all students. Other factors will be disputed. Students should be challenged by their classmates to demonstrate evidence that supports their claims. A lively discussion can revolve around the interpretation of evidence. You might ask students how they made sure they were experimenting with only one variable at a time.

At the end of the discussion, you could cut one set of spheres in half or show the class a set that has already been cut. You might choose instead to let the students rely only on the results of their investigation for their information. If you do this, leave a set of spheres available to students during the time the chapter is being studied. If students think of another experiment they can try it.

Mention that scientists studying the earth's rotation can account for the earth's behavior only if the earth's mass is concentrated toward its center. Another support for this inference is the fact that the earth's average density is almost twice the density of the crust.

13–2
Earthquake waves and the earth's interior

Students should be able to distinguish P and S waves before attempting to locate the epicenter of an earthquake in Investigation 13–4.

Physics teachers often have reference materials, film loops, and demonstration equipment for wave mechanics. Some of these will be suitable for use in this section.

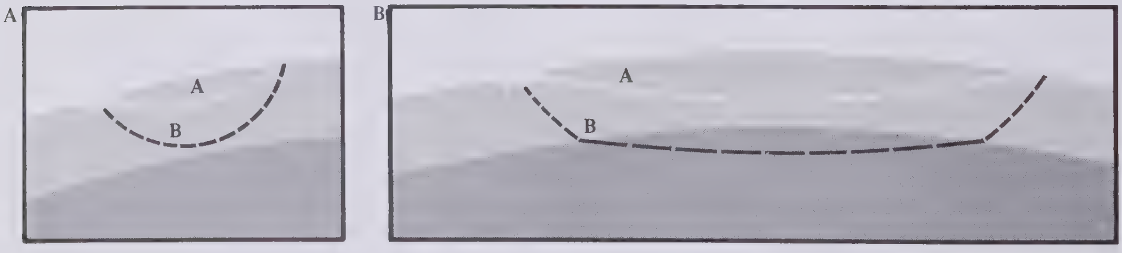
Demonstration A simple demonstration using a long, "slinky" type spring can be useful in explaining wave properties. Suspend a spring from the ceiling or a high cabinet in the room. (The longer the spring, the better this demonstration works.) To make P waves, squeeze several of the loops in the spring together, then release them with a snap. For S waves, flick the spring up and down.

This demonstration is not equally effective with all types of springs. You should try it in advance to observe the results.

Some teachers have expanded this activity by asking the students to determine if there is a difference in the velocity of the waves. By using a number of springs, you could make an investigation out of this activity.

Guide Figure 13–1

A and B are two types of P waves from an earthquake. (Left) A arrives at a nearby recording station first. (Right) B, traveling faster in a deeper layer of the earth, reaches a distant station first.



13–3
The Moho

Guide Figure 13–1 shows how Andrija Mohorovičić discovered how to locate the upper boundary of the earth's mantle. In Guide Figure 13–1A the two types of P waves from a nearby earthquake did not arrive at the surface at the same time. As you might expect, B, the wave that took the longer path, arrived later than A. When Mohorovičić measured the arrival of P waves from a distant earthquake (Guide Figure 13–1B) he noticed something important. Wave B arrived first. Scientists knew that seismic waves travel at different speeds in different kinds of rock. Mohorovičić reasoned that Wave B must have gone deep enough to enter a different kind of rock. In that rock waves travelled faster than they could near the earth's surface.

Students may be confused by the term *discontinuity*. It means an interface where the physical properties of a material change markedly.

13–4
Locating the epicenter of an earthquake

Advance preparation

Assign the travel time graph and the questions in the investigation as homework. Prepare a graph yourself and locate the epicenter.

Time requirements

Pre-lab	25 minutes
Lab	15 minutes
Post-lab	5 minutes

Materials

The following materials will be needed by each group of two students:

- Graph paper
- Globe from Globe Kit
- Marking crayons
- String

Special notes

The investigation is written for a globe with a 20-centimeter diameter. If students use another size globe, you will have to help them make corrections in the scale.

Pre-lab discussion

Discuss any problems students had preparing the travel-time graphs and answering the questions.

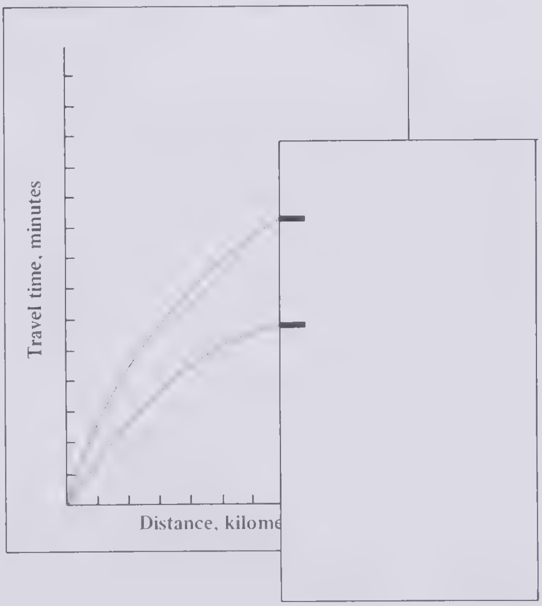
Notes on procedure

The first step in locating the epicenter is to have students note the time difference between arrival of P and S waves for each of the three seismograms shown in Figure 13–4. You might ask students what the time difference shows. The difference between P and S wave arrival times indicates the distance of a station from the epicenter.

To measure the distance of each station from the epicenter students locate the arrival-time difference on the travel-time graph. Then students can find on the graph the distance at which this difference will occur.

Perhaps the easiest way to read distance from the travel-time graph is to lay a piece of paper along the time scale. Mark the interval that represents the difference in arrival time. Then slide this paper up along the curves until the distance between curves matches the time interval marked on the paper. Read the distance on the distance scale. Guide Figure 13–2 shows how this is done.

Guide Figure 13–2
To read a travel-time graph, slide the marks indicating delay time along the two curves on the graph. The marks meet the curves at the distance. Be sure not to slant the paper with the marks.



An alternate method is to have students graph the arrival-time *difference* for each distance. Then students can read the distance directly from the graph.

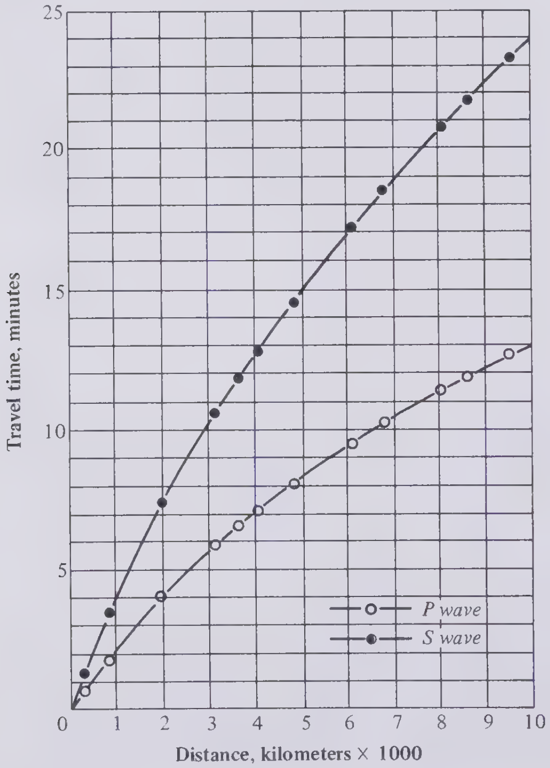
To locate the epicenter students draw arcs on the globes using string as a compass (sketched in the text). One arc should be centered at each seismographic station. For each arc the radius is equal to the distance of the station from the epicenter. The point where all three arcs intersect is directly over the focus. The focus may range in depth to more than 600 kilometers below the surface.

Range of results

Student travel-time graphs should look like Guide Figure 13–3.

If students work carefully, the three arcs will intersect at one point. The epicenter is located about 66.3N latitude, 19.6W longitude. Minor errors in measurements, however, will cause the arcs to form a small triangle near the epicenter location. If this happens, students may assume the epicenter lies within the triangle.

Guide Figure 13–3
Sample travel-time graph for Investigation 13–4.



Post-lab discussion

Students should be able to infer from this investigation that waves travel through the interior of the earth. Once this concept has been accepted by students you might discuss the inferences about the earth's interior based on the behavior of seismic waves.

Students may be interested in knowing that the seismograms used in this investigation actually resulted from volcanic eruptions of Surtsey, near Iceland.

Answers to questions

1. How long does it take for a P wave to travel from the focus of an earthquake to a seismograph station 2000 kilometers away? **Answer** 4 minutes, 4 seconds.
2. How long does it take an S wave to travel the same distance? **Answer** It takes 7 minutes, 25 seconds.
3. What is the difference in arrival time between P and S waves for an earthquake that is 3000 kilometers away from the station? 5000 kilometers away from the station? **Answer** About 4½ minutes. About 6¾ minutes.
4. How is the distance of a seismograph station from the earthquake related to the arrival time of the waves? **Answer** The farther a station is from the earthquake, the greater the difference is between P and S wave arrival time. This relationship is not a simple linear function. A graph is the most efficient method for determining the distance for any particular arrival-time difference.

Suggested additional investigations

A field trip to a seismographic station would be useful at this point in the course. A list of stations is available from the U.S. Coast and Geodetic Survey.

13–5
Earthquakes and the rock cycle
13–6
Earthquake intensities

If you showed the film *How Solid is Rock?* earlier in the course, remind students of how a solid

can flow like a liquid under some circumstances. This is a good time to show the film if you haven't shown it earlier. *Why Do We Still Have Mountains?* is another film you could show at this time.

When you discuss the Richter Scale of earthquake intensity you should point out the remarks column in the table. The energy equivalents there are very approximate descriptions. It is tremendously difficult to compare energy released by an earthquake to blasts of TNT.

Students may wish to use the information from the Earthquake Watch (Section 11–5) to discuss where the processes listed in Section 13–5 are occurring.

Action After analyzing what happens when you stretch a rubber band, students should recognize the analogy to movements within the earth's crust. How fast the rubber band is stretched has no effect on the amount of energy stored. In the same manner, only the speed with which energy is released by crustal movements determines whether noticeable earthquakes will occur.

If you are apprehensive about paper wads being launched in the classroom, you can substitute other materials. Silicone putty, bubble gum, and springs all give evidence of energy build-up and will break if energy is applied too rapidly. Another example you could use is a plastic ruler. Bent over the edge of a desk or table, it will vibrate when released, regardless of how long the energy was applied to it. If you apply too much energy, however, the ruler breaks.

Demonstration Have students build two identical model buildings with plastic toy bricks. Add decorative cornices (clay or wood), clay statues, and different sized chimneys to one building. Shake the table lightly. Have students observe what happens to the decorations and the buildings. Continue shaking until the buildings are demolished.

Rebuild the buildings, only this time add to one building horizontal beams extending from wall to wall. Anchor the beams to the walls with cellophane tape. Shake the table again. Which building resisted better?

Answers to thought and discussion

1. If a seismic wave travels faster in olivine than it does in quartz, what does this tell you about the density of olivine? **Answer** Olivine is denser than quartz.
2. Why do scientists think the earth's inner core is mostly iron? **Answer** The speed of seismic waves passing through the earth's inner core is about the same as that of seismic waves passing through iron.
3. Where do you think scientists should start to drill if they want to reach the Moho in the shortest distance? **Answer** In the ocean, where the crust is thinner than the continental crust.
4. If you were building a house near the San Andreas fault zone, what are some of the things you could do to make the house "earthquake proof"? **Answer** You could use materials which would vibrate with the earthquake. Buildings built of rigid materials are more likely to collapse.
5. Do you think people should live in active earthquake zones? **Answer** This is an open-ended question, but be sure to ask students who answer "no" what they would recommend to families and businesses in San Francisco. If students answer "yes" you might ask if they think construction standards in such an area should be the same as elsewhere.

13–7
The earth's nuclear powered heat engine
13–8
Taking the earth's temperature

Demonstration Students can make a model of Lord Kelvin's approach to the problem of determining the earth's age. Fill a small beaker with hot water and measure its temperature every two minutes for ten minutes. Graph the results. Can students calculate from the cooling rate how long cooling has been going on? What problems do they find? What must they assume?

In order to understand what forces in the earth produce such changes as volcanoes and earthquakes we must understand something about the earth's heat budget. The most important energy source of the earth is the heat released by the radioactive disintegration of matter. Energy may take other forms as well. Gravitational energy and the kinetic energy of rotation and revolution are just a few examples. What other examples can students name? Overlying materials could compress and heat the interior of the earth, even if the earth formed from particles that were cold at the start. If the earth were hot when it formed, some of that heat would remain. This heat would remain even after five billion years because rocks are very poor conductors of heat. They retain the heat.

The heat that flows from the earth's interior to its surface escapes into space. This process is called *terrestrial heat flow*. This is the quantity of thermal energy that the earth is losing. In terms of the earth's heat budget, it is the heat expenditure.

This flow of heat through the earth's surface is so slight that it cannot be measured directly. However, the rate of heat flow can be calculated.

To do this scientists drill a bore hole into rocks where the heat flow is to be tested. Temperature measurements are made at the top and bottom of the bore hole. The difference, divided by the depth of the hole, gives the thermal gradient. The ability of the rock in that location to transmit heat is determined in a laboratory. This figure is multiplied by the thermal gradient to give the rate of heat flow.

Heat flow measurements have been made on the continents for many years. More recently, techniques have been developed for measuring the flow of heat through the ocean floors. Instead of a drill hole, scientists sink a steel probe a few meters long into the soft sediments of the ocean floor. The probe has thermal sensing elements at each end. The temperature difference between the ends of the probe is automatically recorded. The sediments are collected so their thermal conductivity can be measured.

13–9
Heat flow provinces

Studies of heat flow are another test scientists are using to investigate the theory of plate tectonics. You can refer back to Chapters 10 and 11 to refresh students on the importance of trenches, mid-ocean ridges, and other geologic features mentioned in this section. If you haven't shown a film on crustal movement you might show one of those listed in the Supplementary Materials for Chapter 11.

Answers to thought and discussion

1. How can solid rock flow? **Answer** Solid rock can flow if enough pressure is applied to it for a long enough time.
2. How do magnetic studies support the theory of plate tectonics? **Answer** The magnetic stripes found on the ocean floors record periods of normal and reverse polarity of the earth's magnetic field. These magnetic stripes are older farther away from the mid-ocean ridges and spread away from them.
3. What is one major source of the earth's interior heat? **Answer** Decay of radioactive material.
4. If convection cells are operating within the earth, and they suddenly reversed direction, what effect do you think this would have on the earth's surface? **Answer** Zones of compression and sinking would become zones of expansion and upwelling and vice versa. North America and Europe might start to move back together again.

Discussion of unsolved problems

It must be emphasized that any attempts to predict earthquakes are still very much in their infancy. Many observations of earthquake "warning signs" have been made *after* a large quake, but so far none of these has been useful for predicting other earthquakes.

Some scientists believe that by lubricating faults with water, tension in the area may be released through a series of small movements. They hope small movements that would not cause much damage might prevent a single, disastrous quake.

By recording stress changes along known faults, some seismologists think a large quake can be predicted. They have suggested putting strain gauges on each fault in the area of the San Andreas Fault Zone, for instance.

Answers to questions and problems

A

1. What is the major source of heat in the earth's interior? **Answer** Most of the heat in the earth's interior comes from radioactive breakdown of elements. As radioactive isotopes decay into stable isotopes they give off heat energy.
2. What type of rock contains the highest number of radioactive isotopes? **Answer** Granitic rock.
3. If the continental rocks contain a larger number of radioactive materials, how can the heat flow from the oceans and from the continents be approximately equal? **Answer** The heat flow measurements may be equal because of sea floor spreading. Molten material is extruded from the mid-ocean ridges as the sea floor spreads away from the ridges. This makes the oceanic crust at the mid-ocean ridges hotter than the continental crust. The oceanic crust cools slowly as it spreads.
4. What methods can be used to measure the earth's temperature directly? **Answer** The earth's temperature may be measured directly in drill holes, mine shafts, tunnels and oil wells.
5. What explanation is given for the fact that S waves do not pass through the earth's core? **Answer** S waves cannot pass through liquids. Since they do not pass through the core, the core is said to be a liquid.
6. Why is it easier to measure heat flow in the ocean basins than on the continents? **Answer** Oceanic heat flow measurements are easier to make because the oceanic floor maintains a constant temperature. Its temperature does not change with the seasons, or because ground water of different temperatures moves through it.
7. What is the geothermal gradient? **Answer** The geothermal gradient is the rate the earth's temperature increases with depth below the surface.
8. Name some areas on the earth's surface where you might expect heat flow to be high. **Answer** Heat flow may be high on mid-ocean ridges, the Columbia Plateau, and the Basin and Range Provinces.
9. Why can a compressional wave travel through liquids? **Answer** A compressional wave can travel through liquids because it vibrates in the same direction that the wave is moving.

B

1. What is the difference between compressional and shear waves? **Answer** In compressional waves particles vibrate parallel to the direction of wave motion. In shear waves they vibrate at a right angle to wave travel.
2. What single fact would you have to know to determine the distance to the epicenter of an earthquake with a travel-time graph? **Answer** If you have a graph of arrival time versus distance, all you would need is the difference in time between the arrival of the P and S waves.
3. How many seismograph stations must record arrival times so that an epicenter location can be determined? **Answer** Three stations are needed.
4. Assuming no erosion, how many earthquakes exactly like the Anchorage earthquake would it take to raise mountains from sea level to heights of the modern day Alps or Himalayas? **Answer** The Alaska earthquake caused a vertical displacement of 38 feet. The number of quakes needed to raise Mt. Everest in the Himalayas to its height of 29,028 feet would be:

   $$29{,}028/38 = \text{almost } 764$$

   The number of quakes needed to raise Mt. Blanc in the Alps to its height of 15,781 feet would be:

   $$15{,}781/38 = \text{about } 415$$

5. At the time of the Good Friday earthquake, there was a meeting of the Seismological Society of America in Seattle. Most of the seismologists did not actually feel the earthquake. A number who were having dinner in the restaurant at the top of the Space Needle did feel it. What would be the Mercalli Intensity rating in Seattle? **Answer** The earthquake in Seattle would be II-III on the Mercalli Scale.
6. What is the difference between the Mercalli Scale of Earthquake Intensity and the Richter Scale? **Answer** The Mercalli Scale measures how earthquake intensity affects man and animals. The Richter Scale measures earthquake magnitude. Magnitude depends entirely on the amount of energy released by the earthquake, not on its effect on man.

7. Can parts of the earth's surface move relative to one another even though an earthquake does not occur? Give an example. **Answer** Yes. Note the winery in Figure 13–5.

C

1. What evidence can you cite to answer the question of whether the earth's interior is liquid or solid? **Answer** (1) The geothermal gradient, (2) movements of the crust and accompanying interior movements, (3) seismic wave behavior in the interior of the earth, and (4) the response of the earth to tidal forces and rotation.
2. The radius of the earth is 6370 kilometers. The location of the core-mantle interface is at a depth of 2900 kilometers. What percentage of the earth's volume is occupied by the core? What percentage is occupied by the mantle? (Neglect the volume of the crust.) **Answer** The volume of the earth, in cubic kilometers, is calculated as follows:

$$V_e = 4/3\,\pi\,R_e^3$$
$$V_e = 4/3 \times 3.14 \times (6.37 \times 10^3)^3$$
$$V_e = 1.08 \times 10^{12}\text{km}^3.$$

The volume of the core is calculated as follows:

$$V_c = 4/3\,\pi\,R_c^3$$
$$V_c = 4/3 \times 3.14 \times (3.47 \times 10^3)^3$$
$$V_c = 1.75 \times 10^{11}\text{km}^3.$$

The per cent of the earth made up by the core is:

$$\frac{1.75 \times 10^{11}}{1.08 \times 10^{12}} = 0.162 \text{ or } 16.2 \text{ per cent.}$$

The volume of the mantle is
$1.08 \times 10^{12} - 1.75 \times 10^{11} = 9.05 \times 10^{11}\text{km}^3$.
The per cent of the earth made up by the mantle is:

$$\frac{9.05 \times 10^{11}}{1.08 \times 10^{12}} = 0.838 \text{ or } 83.8 \text{ per cent.}$$

(You might reach this answer instead by subtracting 16.2 per cent from 100 per cent.)

3. Explain how magnetic evidence supports the theory of sea-floor spreading. **Answer** When molten magma cools at the mid-ocean ridges the magnetic minerals in it are magnetized in the direction of the earth's magnetic pole. The earth's polarity has reversed a number of times throughout geologic time. Scientists have found stripes of normal and reverse magnetization on the ocean floor. These stripes running parallel to the mid ocean ridges indicate that the sea floor must be spreading out from the mid-ocean ridges.

Supplementary Materials

Reference books

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Reiner, Marcus. "The Flow of Matter." *Scientific American*, December 1959. (Also Scientific American Offprint #268)

Wilson, J. Tuzo. "Continental Drift." *Scientific American*, April 1963. (Also Scientific American Offprint # 868)

Films

Earthquakes and Volcanoes. 18 minutes, color. Film Associates of California, 1957.

The Hidden Earth. 29 minutes, color. McGraw-Hill Text-Films, 1960. Views of seismographs, seismic record interpretation, seismic exploration on land and sea, crustal structure, volcanoes, geysers, earthquakes, and Project Mohole.

How Solid is Rock. 22 minutes, color. Encyclopaedia Britannica Educational Corp.

The Interior of the Earth. 14 minutes, color. McGraw-Hill Text-Films. General Science Film Series. How a seismograph works and why seismic waves are transmitted through mantle and core at different speeds.

Other aids

Wave Demonstrator Kit #3200. Macalaster Scientific Company. Useful for demonstrating wave motion.

14. Evolution of Landscapes

Chapter Objectives

After completing this chapter, students should be able to:

1. Explain how the kinds and arrangement of rocks in an area, along with erosion and deposition, contribute to the development of landforms.
2. Construct a topographic map from a three-dimensional model.
3. Use a topographic map to identify variations in landscapes.
4. Identify the dominant leveling process in any landscape.
5. Describe how the rock cycle and the water cycle worked together to shape landforms observed in the field, in photographs, or on topographic maps.
6. Recognize the landscapes typical of mobile belts and stable areas.
7. Rank the relative importance of streams, glaciers, wind, and waves in producing landforms.

Teaching the Chapter

Whether your school is in a city or in the country it is surrounded by a landscape. That landscape is a record of change. You can cover the topics in this chapter using examples from your local landscape. Try to have topographic maps of your local area on display in the classroom. Topographic maps of areas with contrasting landscapes should also be available. These maps can be selected to illustrate typical landscape regions of the United States.

In this chapter students investigate how the rock cycle and the water cycle produce many different types of landforms. Students begin by using three-dimensional models of landscapes. They interpret maps and make a contour map of an object. Students simulate many water-carved landscape features using a stream table. Finally, they analyze actual landscapes observed through stereo viewers.

If you can, arrange a field trip to observe landforms and rock exposures.

Suggested time required

It should take six to ten periods to discuss the topics and complete the investigations in this chapter.

Section Notes

14–1
Growth versus breakdown

Why did the stream across Wheeler Ridge abandon its course through the western notch? Students may suggest several possible answers based on the evidence available. (1) As the ridge rose it widened. You can see this if you compare the width of the eastern tip of the ridge with the width of the ridge at the western gap. To maintain its course through the gap in the widening ridge the stream had to erode more and more rocks. If this became too difficult the stream would have been forced to find an alternate course around the end of the ridge. (2) The older rocks in the core of the anticline may be

more resistant to erosion. As the stream eroded deeper into the anticline it encountered these resistant rocks. It took less energy to change course than it would have taken to erode the resistant core. (3) The rate of rise of the ridge may not have been constant. The stream may have been able to maintain its course through the western gap during periods when the ridge was rising slowly. However, a period of more rapid rise would exceed the capability of the stream to maintain its course. The effect of this accelerated rise would be increased by the widening of the ridge as described in answer (1). (4) Finally, the climate may have become drier as the ridge rose. The stream would have decreased in volume and had less ability to erode its course. A decrease in volume combined with a widening ridge would have made a change in course inevitable.

Which answer is most likely true? Analysis of the rocks in the anticline would be a simple test for answer (2). If the rocks in the core are softer than the outside, the answer is unlikely. If the drainage changes are the result of a single factor, answer (1) is the most likely explanation. It is a significant factor in each of the other answers. Any combination of the answers could have caused the change. We do not know the facts necessary to be more explicit.

14–2
Investigating maps as models

Advance preparation

Carefully study all of the questions and answers in this investigation. It is important for you to become familiar with the procedure before the investigation.

You can construct model mountains of plaster or modeling clay if you do not have the Contour Model Kits.

Time requirements

Pre-lab	10 minutes
Lab	35–40 minutes
Post-lab	10 minutes

Materials

The following materials will be needed by each group of two students:

- Transparent box with lid from Contour Model Kit
- Stereo viewer and stereo atlas from Stereo Photo Kit (optional)
- Marking crayon
- Clear plastic sheet
- Plastic volcano model from Contour Model Kit
- Food coloring (optional)
- Masking tape
- Water

Special notes

The model mountain may float. Students can fasten it down with tape or hold it down.

Water-base ink or marking pens will not work on the mountain, since the color runs. Use pencils, crayons, or other waterproof marking pencils instead.

Pre-lab discussion

You can begin by discussing the answers to questions 1, 2, and 3 with the class. Most teachers find it effective to go directly from there into the contour procedure. Some, however, prefer to discuss question 4 before moving ahead.

Notes on procedure

Let students work out their own definition of contour lines. The method they use to draw the map is as follows: Have students make a series of marks 1.5 centimeters apart up the side of the box. The spaces between the marks are contour intervals. Then place the mountain model inside the box and fill the box with water to the first mark. A few drops of food coloring in the water makes it easier to see the water line. With the marking crayon draw a line around the model mountain at the water line.

Students should repeat this procedure for each level until the model mountain is covered with water. Then put the lid with the clear plastic sheet taped to it on the box. Trace the contours as they appear from above.

It is a good idea to treat the first seven questions and their answers as procedural instructions. You can discuss them with the class as they work through the investigation. Additional teaching suggestions are included in the answers to the questions.

Range of results

A contour map of the model mountain is shown in Guide Figure 14–1. Some similarity should be evident between this figure and maps the students make. Students' contour maps of the model mountain should be similar to one another also.

Post-lab discussion

The discussion should focus particularly on the answers to questions 7 and 8. If you feel the students did not understand other points, you can review them at this point in the investigation.

Students can see a three-dimensional view of the Red Rocks area in the stereo atlas. Have them compare what they see through the stereo viewer to the photography in Figures 14–5 and 14–6 and the topographic map in Figure 14–7. Which kind of model do the students think most clearly shows what the area looks like?

Answers to questions

1. If you were asked to make a model of the earth's surface as seen in Figure 14–5, how would you do it? **Answer** Students might suggest making clay or plaster models, or making maps. The title of the investigation certainly will lead many students to suggest maps.
2. What other information would you need to complete your model? **Answer** You need a more detailed look at the region. For example, you need to know something about the region hidden behind the physical features on the photograph.
3. What additional information does Figure 14–6 provide you with? **Answer** Ask students to look closely at Figure 14–5. It might surprise students to learn that a large stream valley lies between them and the sloping layers of sedimentary rock in the distance. None of the roads that completely lace the area is visible in this picture. Neither can you see a 15,000-person outdoor amphitheater (Red Rocks Theater). These are visible in Figure 14–6. The arrow in Guide Figure 14–2 shows the location of the camera for Figure 14–5. However, the viewer still cannot see around the corners to make a model. Students can create a mental model of the area by using imagination. If some students have had experience with terrain similar to this, their mental models will be more similar to the actual area than those of students not familiar with it. If the students lived in the area of the photograph, or in a similar area, their mental models should be quite accurate.
4. How does a topographic map show hills and valleys? **Answer** Through the use of contour lines. (See Guide Figure 14–1.)
5. How does your map of the model mountain compare with the topographic map? **Answer** Your map shows only contours, and its scale is the same as the model itself. The topographic map shows streams, roads, houses, and many other features of the landscape. The

Guide Figure 14–1
Contour map of the model mountain.

Guide Figure 14–2
The arrow shows the location of the camera for Figure 14–5 in the Text.

scale is much smaller than the actual landscape. Students also might mention that the contours on the topographic map measure the height above sea level. On student maps the contour lines mark intervals above the bottom of the box.

6. How would you define a contour line? **Answer** A contour line is a line on a map connecting points of equal elevation.
7. Discuss the statement: "A map is a paper model of the real world." **Answer** Students should be able to discuss the advantages of representing features such as hills with contour lines. They also should realize that each type of representation has things it cannot show.
8. How do each of the maps in Figures 14–9 and 14–10 represent the world we live in? How are they useful? **Answer** A weather map summarizes precipitation, temperature, wind direction, and frontal conditions. It is a descriptive model of the conditions on the earth's surface at any particular time. From a series of weather maps of a certain area you can establish weather patterns. From the patterns meteorologists make predictions of future weather conditions. These predictions are valuable to agriculture, transportation, business, and industry.

   A geologic map represents the rocks of the crust at the earth's surface. Geologic maps usually do not show soil or other materials that overlie rock. Geologic maps can help geologists identify economically useful rock formations and interpret how they originated. Sometimes this kind of model barely resembles what you actually see. This geologic map shows the same area in the Morrison Quadrangle that the students mapped. Have them compare the two maps and the photographs.

SUGGESTED ADDITIONAL INVESTIGATIONS

You could expand this investigation by asking students to draw a cross section of the land shown in Figure 14–6. The cross-section should show a topographic profile of the ridges and the plain to their east. It should resemble Guide Figure 14–3.

14–3
Mountains, plains, and plateaus

A selection of good relief and topographic maps of the United States will be of assistance when students discuss this section. Some maps you may want to locate for your classroom are listed in Chapter 16 of the *Geology and Earth Science Sourcebook*, listed in Supplementary Materials.

Topographic maps of the area around your school may be sold in a local bookstore or camping supply store. They can be ordered from the Map Distribution Section, U.S. Geological Survey, Washington, D.C. 20242, for areas east of the Mississippi River, or Denver Federal Center, Denver, Colorado, 80225 for the rest of the country.

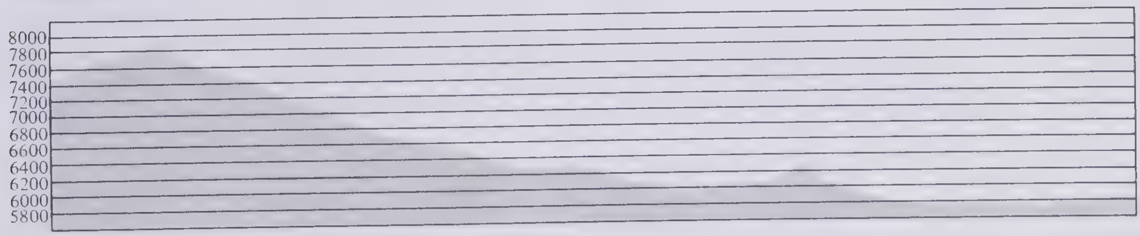
Also try to find photographs showing examples of mountains, plains, and plateaus. Arrange them on a side table or a bulletin board so students can browse.

One question you might ask students is how they can distinguish a plateau from a plain in a photograph. Can they be told apart on a map? What characteristics are common to both?

Answers to thought and discussion

1. Look again at the ridge in 14–1. Suppose that uplift began at the same time for all parts of the ridge but was more rapid toward the west end. Would this account equally well for the present landscape? **Answer** Different rates of rise along the ridge would not have changed its erosional history.
2. If the processes of weathering and erosion have been acting on the land areas for billions of years, why do we find high mountain ranges today? **Answer** The forces that lift up mountains have been acting on the land areas

GUIDE FIGURE 14–3
Cross section of the land shown in Figure 14–6 of the Text.



just as long as the forces that wear mountains down.
3. Most of the area in Figure 14–7 is underlain by sedimentary rocks. How do the landforms show the effects of tilting and differences in resistance to erosion? **Answer** The parallel ridges show the edges of tilted sedimentary layers. The asymmetric shape of the ridges is caused by the layers' unequal resistance to erosion. You can see the layers of rock parallel to the crest of the ridge in Photo 19 of the stereo atlas.

14–4
The parts of a landscape

Most of the class discussion will center around Figures 14–14 and 14–15.

Action If the class was able to observe local landforms ask students how they recognized areas receiving sediments. What information would students need to determine how long it took for the landscape to form?

If students observed stream intersections you may wish to introduce and discuss Playfair's Law. The following is a statement of the "law" published by John Playfair in 1802. You might ask students to rewrite the law in their own words.

> "Every river appears to consist of a main trunk, fed from a variety of branches, each running in a valley proportioned to its size, and all of them together forming a system of valleys, communicating with one another, and having such a nice adjustment of their declivities, that none of them join the principal valley, either on too high or too low a level; the circumstance which would be infinitely improbable, if each of these valleys were not the work of the stream that flows in it."

14–5
Investigating areas of erosion and deposition

Advance preparation

Have students prepare a half-dozen buckets of loose soil or fine sand. The soil should be a uniform mixture of sand, silt, and clay.

Place the soil or sand in a flattened mound in the upper part of the stream table. Have mops and paper towels available for cleanup.

Time requirements

Pre-lab	5–10 minutes
Lab	30 minutes or longer
Post-lab	10–15 minutes

Materials

The following materials will be needed by each group of five students:

- Stream Table Kit or:
  - Tray with drain at one end, approximately $122 \times 36 \times 9$ cm
  - Siphon tube with clamp, approximately 2 m $\times$ 1 cm in diameter
  - Support to raise one end of tray
- Soil, a bucketful, approximately 10 kg
- Catch bucket
- Water
- Polaroid camera (optional)

Special notes

The tray should be well supported to prevent sagging or tipping.

The "pond" should catch most of the particles that wash down. If any are carried through, they may clog the sink. To avoid this, drain the tray into a bucket in a sink. Have students empty the buckets carefully into the sink to avoid plugging up the drain.

Pre-lab discussion

Review with students how you tell the boundary between erosion and deposition in a landscape.

Groups may choose to investigate different factors such as stream slope, discharge, channel shape, or coarseness of materials. You might ask students how they plan to vary only one factor at a time.

Notes on procedure

Have each group of students record their observations of erosion as they go along.

Much of the success of this investigation depends on your effectiveness as you circulate among students during the investigation. Constant questioning about the erosion-deposition boundary will focus the students' attention on the effects of the factors that they vary during the investigation. Point out that in their model landscapes students can see the effect of interaction between the rock cycle and water cycle. As you circulate, encourage students to share what they

observe with other groups. You could, for example, ask how the changes observed on the stream table could be produced in nature.

When the laboratory time is nearly over, students can empty the lake and carefully slice the delta apart to see if its internal structure is visible.

If a Polaroid camera is available, you can take a sequence of photographs showing the changes in the appearance of the stream tables. One way to use the photographs is to mount them on heavy cardboard. Then they can serve as a base for acetate overlays the students can draw on with grease pencils. Later you might ask students to put them in a time-ordered sequence.

Range of results

There should be a wide range of results since students may choose to vary different factors.

Post-lab discussion

Have students point out interesting features that developed on their trays. Examples of observations students may make include undercut banks, areas of temporary depositions, and erosion around pebbles or other obstacles placed in the soil. How did various factors influence the change of position of the erosion-deposition boundary?

The observations should include a discussion of the processes and features found in natural streams.

Suggested additional investigations

Some teachers recommend allowing the class access to the apparatus for several days after the investigation. Students who are interested can study more details about erosion and landscape evolution.

The class can observe more realistic erosion if you can set up one stream table as a demonstration. Keep the water flow constant and let it run for several days. Have students compare the changes in this table to their observations during the investigation. A series of Polaroid photos of the tray will be helpful.

14–6
Rates of change

Ask students to list examples of erosion. Then see if the class can arrange the items on the list in order of their rates of occurrence. You could ask questions such as: How can these rates be expressed? Do they occur in seconds or in millions of years? Could you observe change in any of the examples during the school year?

Show the film *Erosion — Leveling the Land* (listed in Supplementary Materials) when you discuss this section if possible. Before you begin the film, ask students how they would film long term erosion if they were making a movie. Time-lapse photography is one common technique.

14–7
Landscapes and climate

Most landscapes develop through a sequence of stages. The major stages may be called "youth," "maturity," and "old age." A youthful landscape is a newly uplifted plain. Erosion begins with the development of a few stream valleys. These valleys are separated by broad areas of the plain. As tributaries develop the original plain slowly disappears. New flat areas may begin to develop along the bottoms of the major stream valleys. Eventually the area is almost all sloped with only small remnants of the original plain and equally small areas of low flats along streams. This stage is called maturity. Figure 14–18 shows a mature landscape. Continued erosion will remove all of the material remaining above the low flat. The result is a new, lower plain. This is old age.

Different landscapes may progress through these stages at different rates. The stages do not represent an amount of time, but a sequence. One stage may last much longer than another. The most important factors determining how fast a landscape ages are moisture, climate, elevation, and the nature of the material being eroded.

Landscapes developed in dry and in humid regions are easy to tell apart. But in either climate the character of the landscape is determined almost entirely by erosion by streams. Glaciers, wind, and other agents of erosion may modify landscapes shaped by streams. Only rarely is any of these a major factor in developing a landscape.

In most landscapes the valleys develop in patterns which reflect the arrangement of the rocks being eroded and the climate. These two factors usually determine how many stream valleys there will be in an area.

14–8
How low can a landscape get?

Erosion has reduced many regions to gently sloping areas of low relief. In a youthful or old landscape the slopes will be very gentle. Because of this the streams will have low potential for erosion. The slope of a stream determines the potential energy of the water in it. In high mountains the water has high potential energy because of the high elevations and steep slopes. As a region is lowered by erosion the potential energy of the flowing water decreases. Figure 14–21 shows such a landscape.

Proof that erosion can, in fact, produce a plain of low relief over large areas is found in unconformities. The unconformity exposed in the walls of the Grand Canyon is a surface of erosion. The sedimentary rocks of the canyon wall rest across the eroded edges of the folded sedimentary rocks below the unconformity. In other places the rocks of the wall rest on eroded metamorphic and plutonic rocks. (See Figure 14–22.)

Action The diagram students are asked to draw should be similar to the example in Guide Figure 14–4. The three types of unconformity shown are: a) between plutonic rock and younger sedimentary rocks, b) between folded sedimentary (perhaps in part metamorphic) rocks and younger sedimentary rocks, and c) between the undisturbed older sedimentary rocks and younger sedimentary rocks.

14–9
Other landscapes

You might ask students why so few impact craters have been found on earth. Because of erosion, only the most recent craters would be easy to recognize. The dry climate in Arizona allows Meteor Crater to appear essentially unchanged after a few thousand years.

A variety of landforms — sand dunes, sink holes, and many features formed by erosion and deposition by glaciers — are not discussed in the Text. If any of these occur in your locality you could make them a special subject for field investigation. If not, you could investigate them with maps and photographs. Many standard texts will provide the essential information. Several are listed in Supplementary Materials.

14–10
Investigating regional landscapes

Advance preparation

Become familiar with the use of the stereo viewers. Also you should review the physiographic provinces of the United States.

Time requirements

Pre-lab	5 minutes
Lab	45 minutes or more
Post-lab	15–20 minutes

Materials

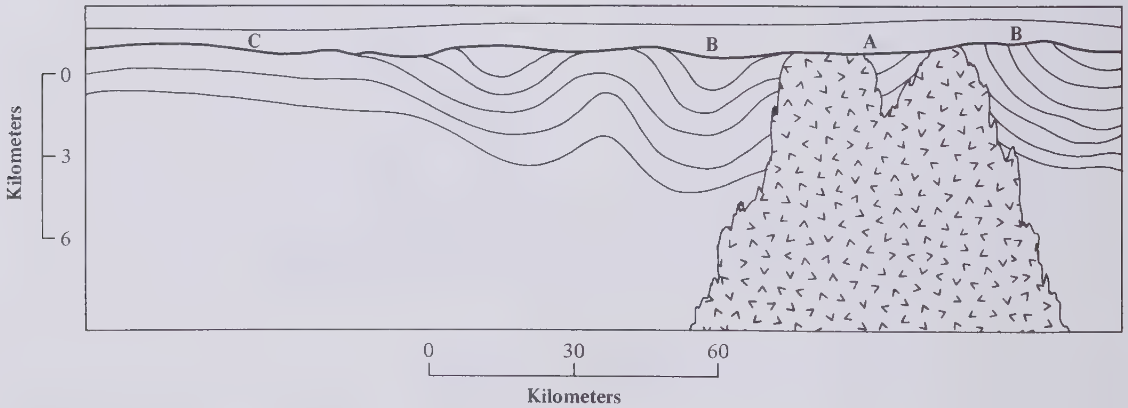
The following materials will be needed by each group of two students:

- Stereo viewer and atlas from the Stereo Photo Kit
- Map from Landform Map Kit
- Clear plastic sheets
- Grease pencils or water soluble markers

Pre-lab discussion

The stereo viewers can cause many problems in

Guide Figure 14–4
Sample diagram of an unconformity for the Action in Section 14–8.



this investigation. Begin by reviewing the instruction page in the stereo atlas.

If there are students in the class who have lived in or visited other areas of North America, ask them to describe the landscapes they saw. There are usually some students who are unaware that other landscapes may be quite different from the one where they live.

Notes on procedure

Students should cover the landform map with plastic sheets to draw in the various landscapes. Marks are easily erased from the plastic if a student decides to move them. Circulate among the students and watch for problems students may be having with the viewers.

Classification of the map into regions should not take more than 10 or 15 minutes. A brief class discussion (perhaps up to 10 minutes) will be useful to compare and contrast various student results. Ask various students to explain why they chose the boundaries and groupings they did.

It is important to allow ample time for students to compare the photographs and maps to the landform map.

Range of results

Guide Figure 14–5 shows a commonly used division of the United States into landscape regions. Students may recognize many subdivisions as well. The important things to look for are relative uniformity within a region and contrast from one region to another.

Answers are included on the following page for three of the photographs. Students should analyze the other photographs in a similar fashion.

Since each area was chosen as typical of the landscape in its province, students may locate it anywhere in that province. For example, the parallel ridges near Harrisburg, Pennsylvania could be located anywhere in the folded Appalachian Mountains, or they might be in the folded mountains west of Little Rock, Arkansas, or in southern California. Further investigation would reveal that the California mountains are in a more arid climate than the Appalachians.

Post-lab discussion

Many of the questions students may have about this investigation will be answered when the class discusses the answers. As the discussion continues students may wish to modify their original division of landscapes. These changes probably will make the map more like Guide Figure 14–5, but many legitimate differences may remain. It is important only that students can logically defend their choice of boundaries.

Guide Figure 14–5
Major landscape regions of the United States.

Location #1 Glenwood Canyon, Colorado

1. Mountain. This is an area of high relief on the western edge of the Rocky Mountains where the Colorado River has cut a deep canyon across a broad anticlinal upland. Remnants of flat areas at high elevations emphasize that this is a maturely dissected area.
2. Sedimentation, uplift, and erosion are evidence of the rock cycle. The uniform thickness of successive layers in the canyon walls is typical of sedimentary rocks resulting from sedimentation in depositional basins. After the sediments were deposited the area must have been subjected to folding and uplifting. It became a broad anticline more than 2000 meters above sea level. After the beds rose from the sea, streams established a drainage pattern. The land continued to rise and the streams cut their courses deeper and deeper. The Colorado River at this point has now cut a deep, narrow canyon across the anticline.

   Does the river represent the water cycle or the rock cycle? The river is, of course, part of both cycles. In one case a drainage system returns precipitation to the ocean. In the other case it is a leveling agent transporting crustal material to a lower elevation.

   Students might be asked how this landscape will change with time. As the stream cuts deeper, the canyon broadens due to weathering. The tributary streams will etch away more and more of the upland.

   The angular and jagged shape of features here is typical of rugged mountain regions. The upland areas are forested, but vigorous erosion continues in the canyons.
3. Running water or streams
4. Uplift is ahead of leveling. This can be seen in the narrow, deep canyons that dissect the upland.
5. At first glance it appears that man has completely avoided this region. However, the topographic map shows several activities of man. The most important is the railroad. You also can see a power plant and a town called Glenwood Springs. Other evidences suggest man is not a total stranger here. Words such as corral, ranch and house can be found on the map. There are also a number of small reservoirs reflecting use of the area by domestic grazing animals.

Location #2 Western Oklahoma and Southwest Kansas

1. This a plains area with lower relief than the area seen at Glenwood Canyon. Here the relief is only tens of meters. At Glenwood Canyon it was hundreds. This area is part of the Great Plains.
2. Weathering seems dominant here. The surface is characterized by a deep layer of soil. Bedrock is not conspicuous. The deep soil layer probably indicates a long, stable period.
3. Running water is the dominant leveling agent. This is indicated by the well-developed drainage system. The absence of vegetation in the eroded areas can be contrasted to the well-vegetated areas between the gullies.
4. Uplift accounts for the present elevation of the area, but the landscape mainly reflects recent erosion.
5. Man has taken advantage of the flat upland areas for farming. Many farms are in the more eroded regions as well. Contour plowing is now employed to prevent excessive erosion.

Location #3 Mount Rainier, Washington

1. This is a mountainous area.
2. Evidences of the rock cycle are the volcanic cone that makes up the entire mountain, the glaciers, and the stream valleys.
3. Glacial ice is the dominant leveling agent on the upper slopes of Mount Rainier.
4. Volcanism has been the process most active in forming the present landscape.
5. This landscape is used only for recreation.

Answers to thought and discussion

1. In what ways are turbidity currents on the sea floor a special case of erosion and deposition by streams? **Answer** A turbidity current is in every sense equivalent to a stream of muddy water flowing across the land. Both are more dense than the fluid above them. Both can

erode and transport rock materials if their velocity is high enough.

2. What is the role of gravity in shaping landscapes? **Answer** Gravity is the force that causes any earth material — air, water, or rock — to move to a point of lower potential energy. Gravity in this way controls both erosion and deposition, the two key processes in shaping landscapes.
3. In previous chapters you have studied features due to deposition or erosion by some of the leveling agents other than streams. Which of these were not influenced in size, shape, or location by earlier deposition or erosion by streams? **Answer** The ultimate answer is almost certainly that *no* feature was not influenced by stream flow. A granite headland being eroded by waves would be a likely suggestion as an exception. However, the location and perhaps the material, of the granite pluton once were influenced by the deposition of sediments in a geosyncline.
4. Which leveling agent is most important in shaping landforms in your locality? **Answer** This is an open question. The most likely answer will be streams. Glaciers and ground water are common exceptions.
5. Under what circumstances could there be radial drainage with streams flowing toward rather than away from a common point? **Answer** This drainage pattern occurs in enclosed depressions. Death Valley in California, Salt Lake Basin in Utah, and the Caspian Basin in Russia are excellent examples. You can observe numerous gullies running down the walls of Meteor Crater in Figure 14–23. Sediment eroded from the walls is deposited in the bottom of the crater.

Discussion of unsolved problems

Complete understanding of landscape development requires cooperation among a growing variety of specialists. Refined investigations of the dynamics of the crust and the mantle below it are necessary to understand how the rock cycle operates to elevate, depress, and deform the crust. The chemical and physical transformations that rock materials undergo in weathering and erosion must be analyzed. When the energy balance of these processes is better known, the rates of leveling processes can be calculated. Scientists eventually will be able to figure the actual time involved in landscape development.

How long does it take to erode a high mountain range to a low, level plain? The answer is much more complicated than just multiplying the average rate of erosion by the elevation of the mountain range. Mountain ranges seem to sit on top of a layer of granitic rocks much thicker than the crust under nearby plains. The mountains have roots of lighter rock extending downward for many kilometers into the denser mantle. As material is removed from the mountains by erosion the total mass of lighter rock, including the root, is decreased. The mountain will be buoyed up by the denser material surrounding the root, and the mountain belt will rise. In the early stages of erosion the rate of rise may be as much as three-fourths the rate of erosion. As erosion continues, the root slowly rises to the level of the bottom of the adjacent crust. The total amount of erosion necessary to flatten mountains is likely to be several times the mountain's initial elevation. Erosion of a high mountain range to a low, level plain may require hundreds of millions of years.

Answers to questions and problems

A

1. How can areas of erosion be recognized? Describe such an area. **Answer** Areas of erosion are usually rougher than areas of deposition. An area of stream erosion can be identified by valleys cut into the surface material. Usually there is a drainage system along which weathered rock is being removed from the area.
2. How can areas of deposition be recognized? Describe such an area. **Answer** Areas of deposition are usually much smoother, with very gentle slopes. The materials of deposition are well sorted. Areas of glacial deposition, however, are rougher. Materials are unsorted and dumped.
3. What are the leveling processes? **Answer** Leveling processes are the external processes

resulting from the water cycle: stream action, glaciation, ground water solution, wave and current action, and winds. They are called leveling processes because of their general tendency to cut down high places and fill in low places. Streams are the most effective leveling agents, while winds are the least effective.

4. What is the lowest elevation to which the leveling processes could possibly erode the land? **Answer** The lowest point in the vicinity. As long as there is a point lower than adjoining areas, it may be filled by the leveling agents under the influence of gravity. This is true for submarine as well as land surface features.
5. What do unconformities indicate? **Answer** They indicate that a period of erosion took place between the time the rocks below an unconformity were deposited and the time the rocks above it were deposited.

B

1. Describe the leveling processes in terms of energy. **Answer** Gravity causes rocks, snow, ice, and water at high elevations to possess high potential energy. As they move downward their potential energy is reduced and they do not have as far to fall. As long as there is a lower point to which they can move, they will tend to do so. Materials on a low, flat plain have low potential energy. Thus the leveling processes, by smoothing and lowering the land, reduce its potential energy.
2. Is it likely that the leveling processes will ever lower all the land to sea level? Explain. **Answer** From what we can observe, the rock cycle has been active throughout the earth's history uplifting the earth's crust. We have no reason to suspect that the internal forces might someday cease. We can find large regions that have apparently remained stable long enough to permit the leveling agents to produce a vast lowland, such as the Canadian Shield. However other areas have been very active.
3. Once sediments reach the ocean, can they still be eroded? **Answer** If they are exposed. We see abundant evidence of this in the lands and mountains all over the world that are composed of marine deposits. These sediments have been uplifted by internal forces. Actually, some erosion can take place without uplift from the sea: In some areas beneath the sea surface submarine erosion, such as by density currents, is effective.
4. What does a region look like in which internal forces dominate external forces? **Answer** Such a region usually is characterized by high local relief and/or high elevation. Any mountains at high elevation, such as the Rockies, Alps, Himalayas, or Andes, suggest that external processes have not kept pace with uplift. A plateau at high elevation, such as the Colorado or Columbia, with its narrow canyons, has been affected little overall by downwearing. However, high elevation is not always required as evidence for recent dominance by the internal forces. The Dead Sea basin, some 400 meters below sea level, and Death Valley, about 90 meters below sea level are good examples. The subsidence of these basins has gone on at a more rapid rate than filling by external processes.
5. What does a region look like in which external forces dominate internal forces? **Answer** Such a region tends to have little relief and to lie at a low elevation. The floodplain and delta of the Mississippi River are examples. There are places, however, such as the Appalachian region where internal processes have not yet succeeded in reducing the land to a general lowland.
6. What evidence indicates that Meteor Crater in Arizona was created by a meteorite? **Answer** There is an abundance of small meteoritic particles mixed in the soil around the crater. Sandstone at the crater rim is shattered. The sandstone in places is fused into glass. In some instances the quartz has been converted to high-density forms of silica.

C

1. How does the kind of rock in a region help to shape the landscape in that region? **Answer** Sedimentary rocks tend to produce characteristic landscapes. Students may supply several of these examples. In flat-lying beds, a dendritic (treelike pattern) drainage develops. The summits between streams have a fairly uniform elevation. Layering is seen in valley walls. If sedimentary rocks are gently tilted,

asymmetrical ridges develop. If the layers are steeply tilted, hogbacks (or approximately symmetrical ridges) develop. If layers are folded, looping ridges and valleys develop.

Also, the kind of sedimentary rock is significant: Sandstone generally produces ridges or ledges, and shale weathers to slopes or valleys. In humid regions limestone weathers into valleys and slopes (or results in sinkhole topography). In arid regions it is more resistant. One of the most prominent cliffs in the Grand Canyon is the Redwall limestone. Igneous and metamorphic rocks have a less predictable influence. The shape they introduce to the landscape depends largely on the shape of the rock mass.

2. How do events within the crust help to shape the landscape of a region? **Answer** Broad regional uplift produces plateau landscapes. Gentle upwarping produces domes or elongated domes. Folding results in patterns such as the Appalachians. Tensional forces tend to produce fault-block mountains and valleys. Volcanic activity tends to produce conical hills if the eruptions are confined to smaller openings, or lava plains or plateaus if the lava issues from fissures.
3. Can you think of conditions under which rocks in a region would not be physically weathered? **Answer** There probably are no conditions at the earth's surface under which there is no physical weathering. However, if a region is reduced to a flat plain and all the particles are reduced to clay, little physical weathering and erosion can take place. Only uplift of the region or lowering of sea level could change this situation.
4. Why might physical weathering stop in a region long before chemical weathering? **Answer** When a region is reduced to a low plain, physical weathering becomes minimal. Chemical weathering remains because water can continue to be effective in chemical action below the surface.

Supplementary Materials

Reference books

Beiser, Arthur. *The Earth.* Time-Life Inc., New York, 1963.

Heller, Robert L., editor. *Geology and Earth Sciences Sourcebook for Elementary and Secondary Schools*, rev. ed. American Geological Institute — Holt, Rinehart, and Winston, Inc., New York, 1970.

Leet, L. D. and Judson, S. *Physical Geology*, 3rd ed. Prentice-Hall, Inc., Englewood Cliffs, N.J., 1965.

Matthews, W. H. III. *Invitation to Geology.* Natural History Press, New York, 1971.

Scovel, J. L., *et al. Atlas of Landforms.* John Wiley & Sons, Inc., New York, 1965.

Shelton, J. S. *Geology Illustrated.* W. H. Freeman and Company, San Francisco, 1966.

Strahler, A. N. *Introduction to Physical Geology.* John Wiley & Sons, Inc., New York, 1965.

Films

Erosion — Leveling the Land. 14 minutes, color. American Geological Institute — Encyclopaedia Britannica Educational Corp., 1964.

Evidence for the Ice Age. 18 minutes, color. AGI-EBEC, 1964.

Measuring the Shape of the Land and *Determining Sea Level.* Color filmstrips with accompanying record and guide. Encyclopaedia Britannica Educational Corp.

Men at Bay. 20 minutes, color. King Screen Productions, 1969.

Rise and Fall of the Great Lakes. 18 minutes, color. Film Board of Canada, 1970.

The Work of Running Water. 11 minutes, black and white. Encyclopaedia Britannica Educational Corp., 1961.

Other aids

The United States Geological Survey distributes a variety of topographic maps and related literature. Prepayment is required on all orders.

All states east of the Mississippi River:

U. S. Geological Survey
Distribution Section
Washington, D.C. 20242

West of the Mississippi (including Minnesota and Louisiana):

U. S. Geological Survey
Distribution Section
Federal Center
Denver, Colorado 80225

unit four

Earth's Biography

15. Measuring Time

Chapter Objectives

After completing this chapter, students should be able to:

1. Propose methods to measure the duration of events and the intervals between them.
2. Explain why time must be divided into units.
3. Use radioactive decay data to determine the age of rocks.
4. Construct a time scale that tells both the relative and exact age of events.
5. Use the Geologic Time Scale to compare the ages and duration of various segments of geologic time.

Teaching the Chapter

In preceding units students examined earth materials and investigated the processes that change them. In this unit they look for evidence in the rock record that the earth developed over a very long time. The chapter discusses time as a way to measure change and vice versa. It also points out the importance of knowing when various earth processes occurred and how long they lasted.

Students calibrate a relative time scale to investigate the difference between relative time and measured time. They simulate radioactive decay rates to learn how earth events can be dated. Students also make a calendar of earth history drawn to scale. This activity gives students a clear model of the length of time represented by the Geologic Time Scale.

Suggested time required

It should take five to seven days to discuss the topics and complete the investigations in this chapter.

Section Notes

15–1
What is time?

To get students thinking about the difference between relative time and absolute time, encourage class discussion of time. For example, pose the question: How can you define time? Students usually find that time is difficult to define because it can be considered in so many different ways.

Action Sketch a table like Guide Figure 15–1 on the board for the timekeeper to use. When the first hand goes up, the timekeeper places a mark in the first column. As more hands are raised the timekeeper places marks in succeeding columns. Leave it up to the timekeeper when to start marking in a new column. (More columns can be added to the chart as needed.) It is important that neither the participants nor the timekeeper see a clock.

During the recording period you should be jotting down the number of hands raised during each 10- or 15-second interval.

Some students will try to measure the five-minute period by counting, using their pulse, or devising some other way of marking time intervals.

Guide Figure 15–1
Table for recording the guesses about the time interval for the Action in Section 15–1.

Others are likely to say they signalled the timekeeper when it "felt like" five minutes were up. When every student has signalled the timekeeper the table will look something like Guide Figure 15–1. The actual times usually vary from about three minutes to slightly over five minutes.

Ask students to interpret the table. Most will assume that each column represents an equal interval of time. They will be curious to know which column contains the accurate guesses. The information on the chart, they will discover, is unrelated to measured time. It gives only the relative numbers of guesses with passing time. All the sample table shows, for example, is that more people thought that five minutes ended within the F interval than any other interval.

In reviewing natural events that represent change and are used to measure time, you might ask students why American Indians referred to past events as being so many suns ago or so many moons ago.

15–2
Relative time — measured time

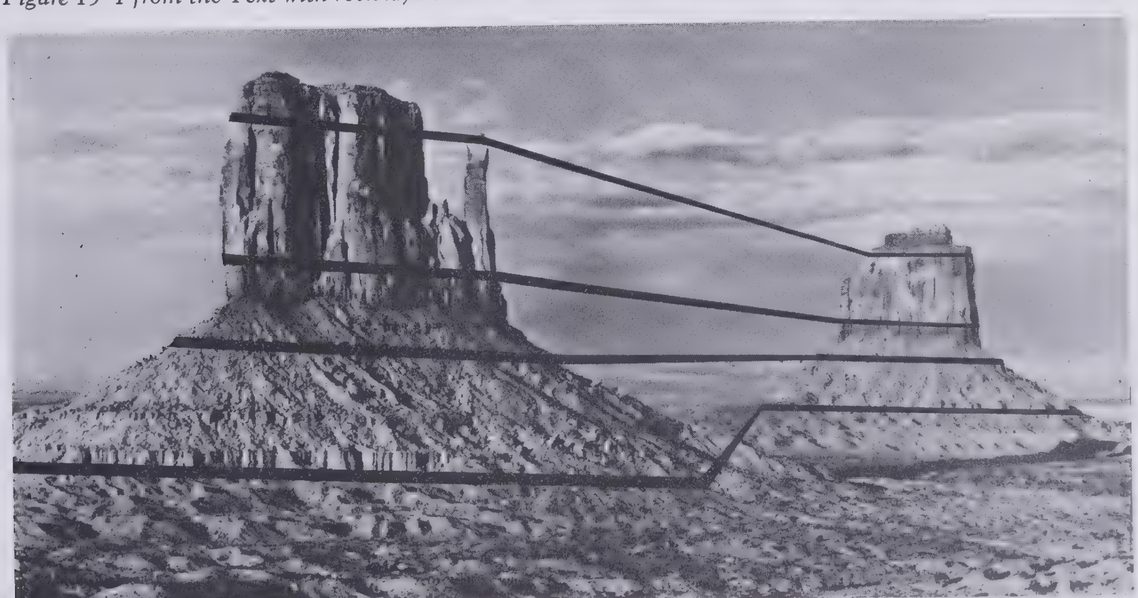
Time is measured as duration. Students may think of duration as the quantity of time that some event occupies. You can compare durations to provide a *relative* time scale.

Action You can vary the procedure to promote more class discussion. For example, put the lists made by three different students on the board. Then have the class arrange all the events into one sequence with the most recent event at the top. An example of a student's list might be, "broke my arm when I was a baby"; "got a new house in grade school"; and "saw the first walk on the moon during my first year in junior high school." Unless they grew up in the same neighborhood, students will have to refer to a measured time scale of months and years to correlate the lists of several students.

Demonstration Students may have difficulty relating relative time to sequences in rock layers. A way to demonstrate a relative time sequence is to show the class photographs of cars or planes, ranging from early models to the most recent ones. Ask students to put the pictures in an ordered sequence. Students will be able to order the pictures in time and determine the relative ages of the objects without knowing dates and ages.

Demonstration In Figure 15–1, the oldest layer of sedimentary rock is at the bottom, as it is in any *undisturbed* sequence of sedimentary layers. Guide Figure 15–2 shows how the rock layers match. You can illustrate the arrangement of the layers by placing pieces of cardboard, books or playing cards one on top of the other. Pause for different lengths of time between each layer. Tell students that the pause represents how long it

GUIDE FIGURE 15–2
Figure 15–1 from the Text with rock layers matched.



took for each layer to be deposited. Ask students to compare the ages of the layers. They will need to know how much time elapsed between deposition of each layer. What more do you need to know to make a measured time scale for the stack?

15–3
Clocks and calendars

You might introduce this section by reviewing the historical development of clocks and calendars. Interested students may want to make an early type of clock — a sundial, water clock, or a candle clock, for instance — for the class. Point out that mechanical devices for measuring time are quite recent developments. One way to do this is to have students match each early clock to an event from the same period in history. What historical events, art, or music would have been familiar to people using each early clock?

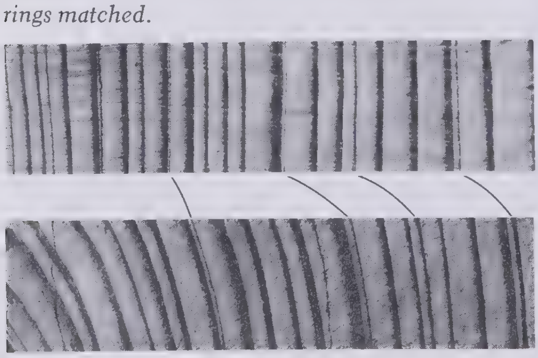
Action Most students will be familiar with the appearance of growth rings. The magnified section of wood in Figure 15–2A shows that growth varies from season to season. The smaller, thicker-walled cells grew in late summer and fall. Wider, lighter-colored bands are the year's spring growth. A pair of bands, including the thick- and thin-walled cells, represents a full year's growth. It is the *pair* of bands that is called a growth ring.

Growth rings also show that growth varies from year to year. The wider the growth ring, the more favorable the growing conditions. Ask students to name some of the factors that affect plant growth.

Since climates vary, it usually is *not* possible to correlate growth rings in one region with those from another. It is possible, however, to correlate growth rings of trees from the same area that lived at the same time. Figures 15–2B and 15–2C show trees that lived at the same time. The growth rings are matched in Guide Figure 15–3.

The shells of some invertebrates (Figure 15–2D) have growth rings, too. These rings are also the result of seasonal variation in growth. The sediments shown in Figure 15–2E were deposited in the bottom of a glacier-fed lake. Like the bands in a tree's growth rings, the sediments show a difference between summer and winter deposits. The dark bands represent sediments with a higher moisture content. A dark band usually is deposited each winter, although a heavy storm could form a dark band at any time of the year.

Guide Figure 15–3
Figure 15–2 from the Text with growth rings matched.



Answers to thought and discussion

1. In a time-ordered sequence of events, event A happened before event B, which in turn happened before event C. Event D, however, happened before event B, but after event A. Can you represent these events in the proper order? Place the most recent event at the top of your list. **Answer** C, B, D, A.
   Some additional questions might be asked when this question is discussed. Once the order of events A, B, C, and D has been established, can we tell anything about the duration of any of the events? **Answer** No. We do not know when any event started or when it ended. Since we cannot tell anything about when any of the events occurred or how long they lasted, is there any value in arranging events in order of occurrence? **Answer** Yes. Such an arrangement provides a relative sequence.
2. Can you think of any events that do not involve change? **Answer** The answer to this question should be "No." Students probably will not arrive at this answer until after they have listed some short-term events that do not seem to involve change. If events that do not involve change are proposed, let the class discuss them and arrive at a decision. Some scientists simply define time as change.
3. Why is it important that earth scientists be able to determine relative and measured geo-

logic time? **Answer** Before scientists were able to measure geologic time it was difficult to explain many natural phenomena. It also was difficult to compare different relative time scales. Being able to date events in terms of years before the present also enables earth scientists to determine how fast something is changing.

4. How would you define time? **Answer** Each student will have a definition based on material presented in the Text and personal experience. Since there are several generally accepted definitions for time, any logical answer is acceptable. Time usually is defined as duration, dimension, or change.

15–4
Radioactive elements and atomic clocks

Action You can make an autoradiogram like the one in Figure 15–3 using the uranium-bearing mineral from the Cloud Chamber Kit or a radioactive sample from your school's physics department. If you use Polaroid film instead of regular film you can develop the picture yourself. After it has been in the drawer with the sample, you must put the film into the camera to develop it. Take a picture in a dark room with your hand held tightly over the lens. Then develop the picture as you normally would. There is no safety or health hazard in using such weakly radioactive materials.

15–5
Investigating radioactive decay rates

Time requirements

Pre-lab	5–15 minutes
Lab	20 minutes
Post-lab	20 minutes

Materials

The following materials will be needed by each group of two students:

Plastic box from Contour Model Kit or a shoebox
Markers from Teacher's Kit or thumbtacks, 100
Graph paper

Pre-lab discussion

Students have used models before. Introduce them to the setup for this investigation and ask how it is analogous to radioactive decay. Do students predict that their results will be similar to other groups' results? Can they predict what will happen to any particular marker?

Notes on procedure

If you use thumbtacks instead of markers, remove those which land with the points down after each shake. (See Suggested Additional Investigations.) Results for the whole class can be shown with a master graph on the board or the overhead projector.

Range of results

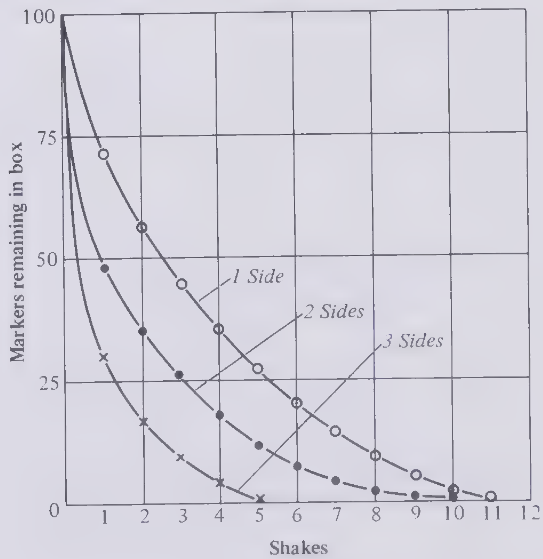
If you plot class averages for each trial, the curves will resemble those in Guide Figure 15–4.

As the number of markers or thumbtacks decreases on later shakes, student results may not be consistent. However, the class's average results will resemble those in the example.

Post-lab discussion

Ask students what significance the shape of the curves has as a model for radioactive half-life curves. How valid is this model? Each marker represents one atom and a period of shaking represents 100 years. Since the periods of shaking were not timed, the half-life is not measured in time but in number of shaking periods. The model, however, does illustrate that decay occurs

Guide Figure 15–4
Sample graph from Investigation 15–5.



at a rate that can be predicted and measured. You might discuss Section 15–6 in conjunction with the post-lab.

You may want to make a transparency of Guide Figure 15–5. Then you can compare the model decay curves to decay curves for various radioactive elements.

Answers to questions

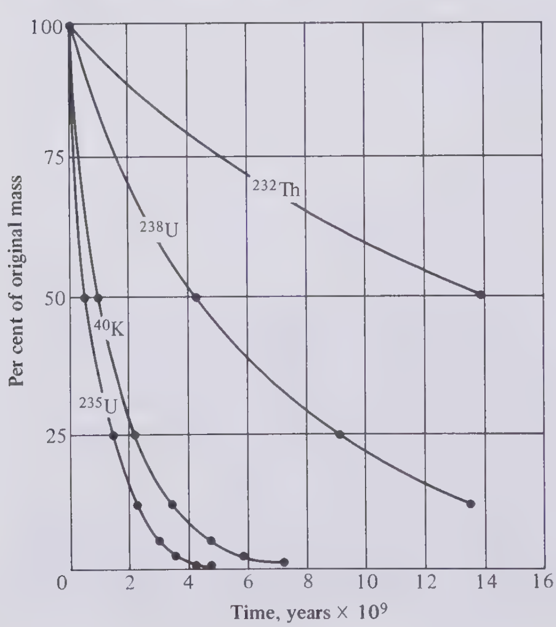
1. What was the half-life for each model? **Answer** Check the graph in Guide Figure 15–4 to determine the number of trials it took to decay half of the markers.
2. How did you change the half-life in the models? **Answer** The half-life shortened as you increased the number of sides that represented decay.
3. What difference would it make in your results if a classmate added some markers to the box during your investigation? **Answer** To obtain useful results, you would have to start measuring decay using the new number of markers.

Suggested additional investigations

Another model of decay can be developed using objects that would have a different probability of removal. You could use tacks, for example, and remove the ones that point to the marked side. Sets of tacks with different head sizes will produce graph curves of different slope. You could use coins and remove the ones that land head up. Or you could remove the coins that land head up and also pointing to the marked side.

Guide Figure 15–5

Decay rates of several radioactive isotopes showing how much of the original material remains as time passes.



15–6
Using atomic clocks to measure geologic time

What could happen to a rock to make its age determination by radiometic dating turn out wrong? Ask your students to propose some natural occurrences that might upset the dating system. All radiometric dating assumes that none of the original radioactive element or its decay products have escaped. It also assumes that no other elements have entered the mineral. Besides assuming these things about the minerals themselves, radiometric dating requires highly precise counting machines. Very small errors alter the results a great deal.

You might mention to students that, in fact, not all samples can be analyzed to produce reliable age determinations. The age determination will be unreliable if decay products have been added or removed. The age will be inaccurate if the sample being measured was formed in a rock at a later time by metamorphism. Refer to question 3 in Investigation 15–5.

Answers to thought and discussion

1. What information besides chronologic sequence can be obtained from tree rings? **Answer** The width of each tree's growth rings shows the conditions at the time the tree was growing. A drought, for example, would produce narrow rings. Ample water and nutrients would produce wide growth rings. Forest fires might scar a tree and leave a permanent record. The age of a wooden building or structure can be determined by radiocarbon dating the wood used in its construction.
2. Can you define the term half-life? Do all radioactive elements have the same half-life? **Answer** The half-life is the length of time it takes for half the atoms of a particular isotope to decay. Half-lives range from very short pe-

riod (^{23}Mg, 12 seconds) to extremely long ones (^{235}U, 7.1×10^8 years).

3. What effect does the radioactive decay of unstable elements in the earth's crust have on the rocks surrounding them? **Answer** Radioactive decay releases energy and decay products that are absorbed by the surrounding rocks.
4. Which method of radioactive dating is used for relatively recent events? Why? **Answer** Radiocarbon dating is used because the half life of carbon-14 is short, approximately 5700 years. This limits radiocarbon dating to the past 50,000 years. The amount of carbon-14 remaining beyond that time is too small to be measured accurately.

15–7
Organizing the rock record

The Geologic Time Scale was developed around 1750. You might ask students if they think this date is when people first discovered fossils. City students may think no one had recognized a fossil before 1750. Students familiar with less built up countrysides may guess that it was unlikely no one had ever noticed a fossil before then. In fact, fossils had been recognized as the remains of ancient plants and animals for many centuries before the Geologic Time Scale was developed.

Fossils, layering of rocks, and depositional processes had been observed as early as the sixth century B.C. Fossil fish from Sicilian quarries and fossil shells from tilted rocks in the Italian mountains are described in writings from that time. Even so, few people understood the very great length of geologic time. For brighter students there are some good primary readings in this area.

The combination of basic ideas of uniformitarianism, superposition, fossil correlation made it possible to organize the rock record. On these principles the Geologic Time Scale was developed gradually from the efforts of many scientists working in different parts of the world.

The units of the Geologic Time Scale were named and put into chronologic order long before it was possible to determine geologic age in years. In fact, today much geologic work is done without reference to measured time. Geologists do not necessarily have to know the age in years of a metal ore or coal deposit in order to find it. They know, for example, that certain Cretaceous or Pennsylvanian rocks contain such deposits. The age of the rock may be a clue to the presence of mineral resources.

One of the historical geology textbooks listed in the Supplementary Materials section can be used to find the age of geologic features that can be seen in your area.

Some students might be interested in reporting to the class on the origin of the names in the Geologic Time Scale.

15–8
Investigating the Geologic Time Scale

Time requirements

Pre-lab	5 minutes
Lab	20–30 minutes
Post-lab	10 minutes

Materials

The following materials will be needed by each group of two students:

- Paper tape from Teacher's Kit, rolls of shelf paper, or adding machine tape
- Meter stick

Pre-lab discussion

Ask several students how long a million years is. How would students count or measure a million of anything?

Notes on procedure

Be sure that students understand how to set up a scale. Reasonable scales are: one millimeter to one million years, one millimeter to ten million years, and one meter to one billion years. Larger unit distances will be easier to work with. Regardless of the scale the students choose, the last million years will be difficult to plot. Check the progress of students after the first few minutes.

Range of results

If students choose a workable scale the first time, they should be able to mark the tapes in one

class period. Guide Figure 15–6 is an example of a typical student tape.

POST-LAB DISCUSSION

One way students can compare their strips of paper is to place all strips side by side on the floor or on a long table. You can tape them to the classroom wall, also. Let students discuss the significance of man's length of existence or the time span of written history compared to the length of the tape.

15–9
Calibrating the Geologic Time Scale

Remind students of the activity in Section 15–2 where they listed four events in order of occurrence. The list was a relative time sequence of events. It was easier to combine several lists when some of the events could be dated accurately.

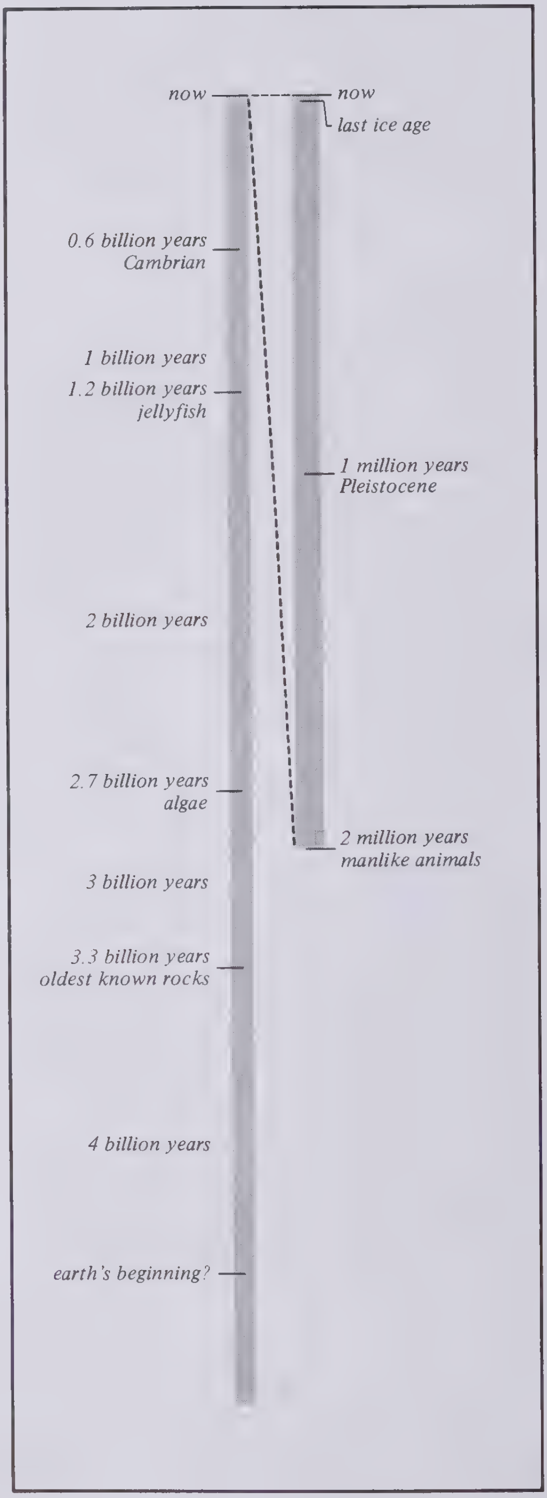
The relative time sequence of the rocks in Figure 15–12 is calibrated in Guide Figure 15–7. The granite intruded rock X and was weathered and eroded before (or during) the time that Y was deposited. Layer Z was deposited on layer Y. Because the granite intruded it, X must be older than 1.5×10^8 years. Rock Z is known to be 1.3×10^8 years old. Since Y was deposited earlier than Z but later than X, its age must be between 1.3×10^8 years and 1.5×10^8 years.

Ask students how the dating of geologic events will help to establish the rates at which geologic processes occur. They should have no difficulty explaining that the dating of two events defines the time span between them.

Answers to thought and discussion

1. Were the earliest methods of classifying geologic time relative or measured? Why were such methods used? **Answer** Earlier time scales were relative, based on the principle of superposition and the characteristics of the rocks. This method was a logical way to try to figure out the age relationships of the rocks in central Europe.
2. How does the correlation of fossil species relate to the development of a Geologic Time Scale? **Answer** At no one place on the earth is the rock record complete. Therefore, it is necessary to correlate rocks from one conti-

GUIDE FIGURE 15–6
Sample tape strip models of the Geologic Time Scale. (Left) A typical scale of one meter to one billion years. (Right) An expanded scale of one meter to one million years to show more detail in the recent past.



nent to another. One way to do this is by fossil correlation. Because fossils in certain rocks can be correlated accurately, the Geologic Time Scale was worked out before radioactive dating was used.

3. How could you develop a Geologic Time Scale for your local area if one were not available? **Answer** First it would be necessary to find out what rocks are present and where they are located. If the rocks in the area are all sedimentary rocks and the structure is simple, a Geologic Time Scale could be developed using the principle of superposition. If the rocks contain fossils, the rock units could be correlated by comparing and matching fossils. If all or some of the rocks in the area are igneous or metamorphic, you must work out the intrusive, extrusive and erosional relationships.

Discussion of unsolved problems

According to astronomers and geologists who are now working on the problem, the age of the earth is between 4.5×10^9 and 5.5×10^9 years. These figures are considerably higher than the ones scientists were quoting a few decades ago. The figures probably will be even higher in the future. As scientists develop more sophisticated methods for determining the age of rocks they find the earth is older than anyone thought. Scientists in the future will know much more about the moon, planets, and interplanetary material. But even with this new information will scientists know definitely how old the earth is? There is good reason to think that they will not.

Many geologic problems will be solved when scientists can date geologic events more accurately. With improved methods geologists will be able to date many rocks in the earth's crust. As a result, scientists should have a better understanding of such factors as rates of erosion and uplift. Dating very old rocks from the ocean floor will help scientists study the history of the ocean basins. Perhaps some of the questions mentioned in Chapter 11 about plate tectonics would then be answered. Nevertheless, because of gaps in the record, some events in geologic history will remain unexplained.

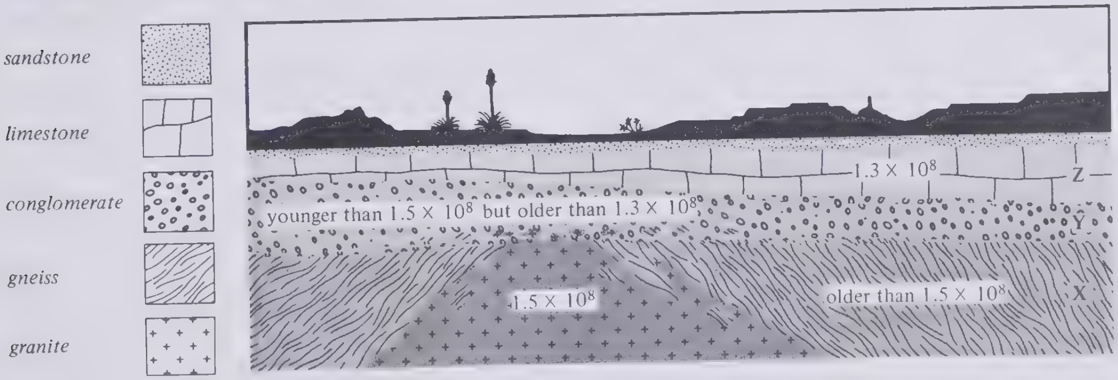
Answers to questions and problems

A

1. Scientists believe that the earth's rate of rotation is slowing down as a result of the moon's gravitational attraction. What effect will this change have on the length of a day? the length of a year? **Answer** The day will be lengthened. As the earth turns more slowly on its axis it will take a point on the equator longer to make one complete trip around the earth. A change in the earth's rate of rotation will also lengthen the year. If the rate of rotation decreases, the radius of its orbit must increase to conserve angular momentum. Kepler's third law, which explains these calculations, is covered in Chapter 20.
2. Why is carbon-14 not used for dating rocks of Paleozoic age? **Answer** The youngest Paleozoic rocks are more than 40 times the age that can be accurately measured by carbon-14 dating methods. The decay rate of carbon-14 is comparatively rapid. Half of the atomic nuclei in any given quantity of carbon-14 decay in approximately 5700 years. Therefore, beyond about 50,000 years the amount of carbon-14 left in any original amount is so small that it cannot be measured accurately.
3. Why is carbon-14 more useful in dating certain earth materials than other dating meth-

Guide Figure 15–7

The relative time sequence of the rocks in Figure 15–12 of the Text.



ods? **Answer** Carbon-14 dating is especially useful in dating rocks that are 50,000 years or less in age because the half-life of carbon-14 is comparatively short. For these materials accurate age determinations can be made. Uranium-238 and most other naturally occurring radioactive isotopes have very long half-lives. Scientists cannot measure the change for periods of time as short as a few hundred or a few thousand years.

4. How old are the oldest rocks dated thus far? Do these rocks represent the original crust of the earth? **Answer** The oldest rocks dated so far are 3.5×10^9 years old. These are granite rocks found in Canada and Africa. They are coarse-grained rocks that must have formed from a magma that intruded into still older rocks and cooled slowly to form the granitic rock. The younger granitic rocks are now exposed at the surface. Scientists cannot say that they represent the original crust.

B

1. Why were earth scientists unable to prove before the year 1907 that the earth was more than 20 to 40 million years old? **Answer** Before 1907, when Boltwood published his finding on the uranium-lead dating method, scientists had no quantitative methods for dating rocks. Rates of accumulation of sediment and similar criteria used to estimate the age of the earth all varied too much to be reliable.
2. Why were many of the early age determinations obtained by the uranium-lead dating method inaccurate? **Answer** This dating method does not take into account the fact that uranium-238, uranium-235, and thorium-232 all produce lead as the end product of their radioactive decay processes. Each radioactive isotope has a different half-life. In addition, helium is also a product of the radioactive decay of uranium. Since it is gaseous, some of it may have escaped from the samples. These potential sources of error lead to inaccuracies in the uranium-lead dating methods.
3. Why is it necessary to study carefully both the rocks and the geology of an area from which a sample for radiocative dating is obtained? **Answer** Before a rock sample can be dated, scientists must know that the sample is uncontaminated and has not been altered in any way. They also must know whether it has been metamorphosed. The geology of the area usually reveals evidence from which to determine these factors.
4. If rocks in other continents contain the fossil remains of large dinosaurs, would they be approximately the same age as rocks in the United States containing similar fossils? **Answer** Yes, because dinosaurs lived only during the Mesozoic Era. The largest dinosaurs were somewhat different on different continents, but they all lived at about the same time.

C

1. Some charcoal and charred, broken bones of deer and rabbits were dug from beneath several feet of sand and gravel along the banks of a river. Analysis of the charcoal in a laboratory showed that one eighth of the ^{14}C remained in the charcoal. How old is the charcoal? Reconstruct the sequence of events that may have taken place at the site of this find. **Answer** Using 5700 years as the half-life of carbon-14, the answer is three half-lives, or 17,100 years. The site was inhabited about 17,000 years ago by a group of primitive men who lived near a river. They cooked deer and rabbits over a fire. Later a flood buried their campsite under sand and gravel. Students may come up with variations that are logical and acceptable answers.

Supplementary Materials

Reference books

Dunbar, Carl O., and Waage, Karl M. *Historical Geology* 3rd. ed. John Wiley and Sons, Inc., New York, 1969.

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Kulp, J. Laurence: "Geologic Time Scale." *Science*, April 14, 1961.

FILMS

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16. The Record in the Rocks

Chapter Objectives

After completing this chapter, students should be able to:

1. Determine the origin of rocks from observing actual rocks or illustrations of outcrops.
2. Distinguish the top of a rock layer from the bottom.
3. Correlate rock layers using fossils, rock types, position in a sequence, or other means.
4. Reconstruct the sequence of a series of geologic events from cross sections of an area.
5. Infer what the climate might have been in the past from fossils and other clues in the rocks.

Teaching the Chapter

In this chapter students reconstruct past events in earth history from evidence in the earth's crust. They also make inferences about past environmental conditions.

Investigations in this chapter emphasize speculation and logical deduction. Students will interpret the Text materials in many different ways. You should encourage this variation. Frequently there is no single, definite answer to a question. Students should examine many possible explanations. Then, using their experience with earth processes, students select the most reasonable one. Students discover that even the most reasonable explanation must be reexamined if new data is collected.

You should include the optional field trip (described at the end of the Section Notes) if it is possible. Field work gives a new perspective to the topics discussed in this course.

Suggested time required

It should take six to eight days to discuss the topics and complete the investigations in this chapter.

Section Notes

16–1
Clues to the origin of rocks

Earlier chapters introduced students to the significance of a rock's texture and mineral content. This section challenges students to see how much they can find out from the photographs in Figures 16–1 and 16–2. You might have students answer Text and caption questions for homework before the class discussion. Logical explanations other than the interpretations in the Guide are acceptable.

Figure 16–1A clearly shows a layered rock outcrop. In a pile of layered rocks, the oldest layer usually is the one at the bottom of the outcrop. Here you can't say for sure which layer is oldest. The fact that the layers are tilted indicates that they have been disturbed. The whole pile may have been turned upside down.

Students are asked to describe relationships among mineral grains in Figures 16–1B and 16–1C. In Figure 16–1B, they probably will not be able to distinguish the fragmental nature of the rock. In Figure 16–1C, they should be able to see that the rock is made up of sand grains and small pebbles. The texture suggests that the rock is sedimentary. It probably formed by the consolidation of loose sand and other materials that accumulated in a depositional basin.

Action Figure 16–2 shows two conglomerates. The well-rounded quartz pebbles in the top photograph probably spent a lot of time in moving water. The presence of sand grains along with the pebbles indicates rapid deposition with little sorting time. The lower photograph shows angular fragments of fossil shells in a matrix of small shell fragments and possibly some sand grains. The shell fragments cannot have moved far after they were broken. The range in the size of the shells indicates that there was poor sorting caused by rapid deposition. The shells probably were broken by waves in shallow water.

Ask students to speculate on how and where these materials may have accumulated. Ask what changes have taken place *since* the materials were deposited. These changes involve compaction and cementation. Cementing materials may be calcite, quartz, iron oxides, or other materials deposited by water. Students may suggest that in many situations it is necessary to use microscopic examination or chemical analysis to read the rock record accurately.

16–2
Layered rocks — pages of earth history

Have specimens of different types of layered rocks available to pass around the class. Ask students to determine what makes the layers visible. Various samples should show layers caused by differences in color, differences in grain size, and differences in the kinds of grains that make up the rock.

The sedimentary outcrop in Figure 16–3 illustrates obvious layering. If the color of the sediments varies as it is being deposited layering will be easy to see. Some rocks have no apparent layering when they are freshly exposed but develop color differences due to weathering. For example, gray and green iron oxides can change to red, yellow, and brown oxides of iron. It is also common for different layers to have differing resistance to weathering. As weathering continues the appearance of the layers becomes very pronounced.

Ask students to describe the shapes of the layers in Figure 16–4A. They should observe that the layers are wavy. If the particles halfway up the small humps are loose and can roll easily, eventually a horizontal surface will be formed as they move down the slope.

When there is a current, as in Figure 16–4B, C, and D, the lower layers are slightly curved. The curvature decreases until the upper layers are nearly horizontal. The potential energy of particles that land on the tops of the humps is high and the particles tend to roll down. Particles that land in the basins tend to remain where they have fallen.

On the basis of the four diagrams, one would expect all layers to be nearly horizontal at the time of their formation. However, particles that settle in quiet water may form wavy layers. The bottom parts of layers formed in areas of moving water may be slightly tilted. Ask students to re-examine the steeply tilted layers in Figure 16–1. Students should be able to conclude that the layers are too steeply tilted to have been deposited in that way. The layers must have been tilted after they were deposited.

The relationship between current velocity and the size of transported particles should be evident from Investigation 10–1. If the velocity of a current suddenly increases, only large particles will settle out. On the other hand, if the velocity of the current suddenly decreases, or if turbulence varies, then smaller particles begin to settle out. Figure 16–5 shows that sand, silt, and clay can occur in the same layer. A single layer can consist of clay (far from the shore) and sand (close to shore). Different parts of the layer were laid down at the same time. As the sediment was washed from the land into the sea, the sand settled out first near the shore. Smaller clay particles later settled at a greater distance from the shore. The interfingering of the clay and sand might show that the sea level had moved up and down at various times, that the velocity of currents carrying sediments from the land had changed, or that at different times particles of different sizes were available.

In the left diagram of Figure 16–7, the flow lines on the surface show that lava probably flowed from left to right. In the right diagram, the orientation of crystals indicates that the lava could have flowed in either direction.

Demonstration You can show the orientation of sticks floating in moving water using a long trough and a stream of water. Put toothpicks in

the flowing water. If the water flows smoothly, most of the toothpicks will float parallel to the current. If there is a great deal of turbulence, many will float perpendicular to the current.

16–3
Cross-beds and ripple marks

Finding the original bottom of a sequence of rock layers is one of the first things a field geologist must do. This section introduces students to more tools to determine the original position of rock layers. Students may want to review Investigation 10–1 by dropping some mixed sediment into a container of water. The results should show the correct position of Figure 16–8. The figure is right side up. If you make an overhead transparency of this figure, you can orient the sketch in any position. Have students analyze each position.

Ask students to look at Figure 16–9 before answering the questions on Figure 16–10. Can they determine the top of the layers from the photograph? What direction did the current flow? Have students describe the sequence of events represented in Figure 16–10. Which is the main bed? Which are the cross-beds? When the main layer in Figure 16–10 is right side up, the concave part of the cross-beds in the lower three diagrams points upward. Even if the diagram is upside down or sideways, the students should be able to identify the top. In the top diagram of Figure 16–10, you cannot tell the top of the layer from the bottom because both are curved.

Use the photograph and diagrams in Figure 16–11 when you discuss how to interpret ripple marks. The current in Figure 16–11 was flowing from the upper right corner to the lower left corner. Students should be able to see the direction of current flow easily when the layer is right side up. However, an asymmetrical ripple can look identical right side up or upside down. Try it.

Symmetrical ripples like those shown in Figure 16–12 have the pointed side pointing up. A symmetrical ripple mark is produced in shallow water when the water moves back and forth.

The lower drawing in Figure 16–12 is right side up, judging from the positions of the fossils. Most of them are concave side down, which is the stable position in moving water. Ripple marks confirm this interpretation. The identification of fossils can help identify the top layers. If relatively young fossils are beneath older fossils, the sequence of layers must be upside down.

Demonstration Use a ripple tank to demonstrate the formation of symmetrical ripple marks. Spread very fine sand or soil over the bottom of the tank. Add several centimeters of water. You might assign several students to produce the marks or do it yourself.

Action When mud dries and cracks, the cracks are relatively wide at the top. They narrow into a V that points toward the bottom of the layer. Have students examine mud cracks in nearby vacant lots or fields. If they are interested in other ways to distinguish the tops and bottoms of layers, you might discuss raindrop prints. The little crater in the center of the splash mark points toward the bottom of the layer.

Samples of cross-beds, ripple marks, fossils, mud cracks, and raindrop prints can be obtained from scientific supply houses. You might also bring slides or photographs of these features to class. It will contribute to Investigation 16–4 if students have seen rock samples showing these features.

16–4
Investigating an ancient stream channel

Advance preparation

Students can trace the outline of the proposed stream channel from the Text. You might prepare a duplicator master or use the transparency master to make copies, instead. Make sure that a ruler is available for each student.

Time requirements

Pre-lab	5–10 minutes
Lab	20 minutes
Post-lab	10–15 minutes

Pre-lab discussion

Students may need help getting this investigation underway. Point out that each marker on

the map represents a place where field observations were made. The direction of current flow was determined from outcrops of sandstone. You might ask students to review Figures 16–9 through 16–12 to understand the significance of this data.

Suggest that they imagine a modern stream that has dried up, leaving sediments associated with stream channels. The main difference between a modern stream and this ancient one is that the sediments in the ancient stream have been cemented together into rocks. To trace the path that the ancient stream followed, students must find the rocks made out of stream-type sediments. Since only a few drill holes were made, students must make some guesses to answer all the questions.

Notes on procedure

Once students have in mind what they're looking for, they usually can trace the stream channel without delay. Students may have difficulty choosing a scale for the cross section. You might suggest that they use a scale of one millimeter : ten centimeters.

Range of results

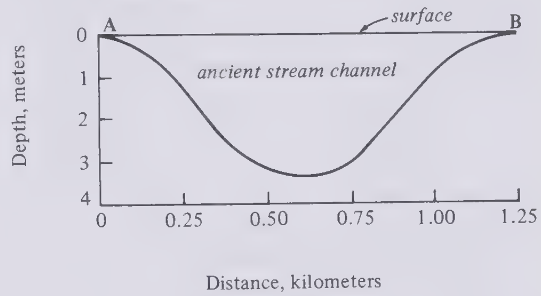
The accuracy of the final drawings will vary. Some students will use all available data while some will be satisfied with approximations. A completed map is shown in Guide Figure 16–1. Guide Figure 16–2 shows a cross section of the stream area through the line A-B. A cross section of any other part of the stream should have a similar shape.

Post-lab discussion

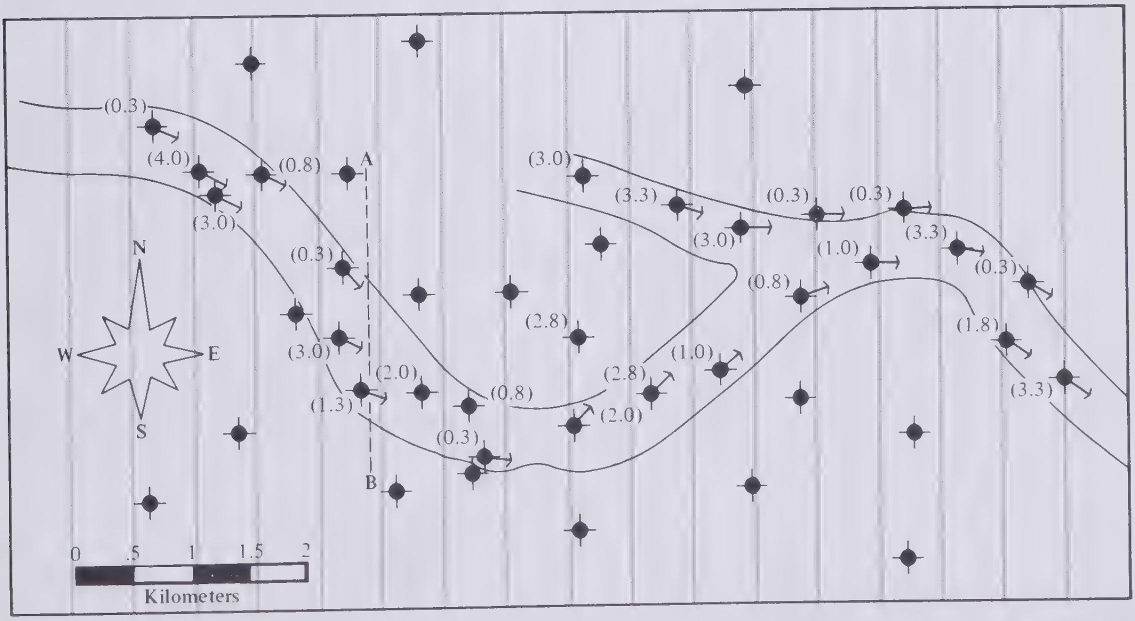
One way to start the discussion is to exhibit a few of the completed maps and ask students to explain how they used the data.

Observe whether the students carefully represent the direction and shape of the channel. They may recognize that the channel boundaries can be approximated simply by connecting each

Guide Figure 16–2
Sample cross section of the buried stream channel. This graph is drawn at line A–B in Guide Figure 16–1.



Guide Figure 16–1
Location of the buried stream channel in Figure 16–13 of the Text.



location where standstone occurs. More accurate channel boundaries can be drawn when the relationship between the thickness of the sandstone and the shape of the channel is taken into account. (Students already have determined the shape of the channel by drawing the cross section graph.)

You might show the film *The Petrified River — The Story of Uranium* as part of the discussion.

Answers to questions

1. What evidence can be used to locate the buried stream channel? **Answer** Stream-type sandstone, ripple marks, and cross-bedding are indicators. The last two show that the stream flowed eastward.
2. How do you know where to draw the lines showing the ancient stream channel? **Answer** Enough data on the location of sedimentary rocks and the direction of ripple marks is provided so that students can produce a map reasonably similar to the one in Guide Figure 16–1. There is no way to be sure that the map is exactly accurate. Students may have logical reasons showing why one version is better than another.
3. Did the ancient stream meander in loops, or did it flow in a straight line? **Answer** The data indicates that it had looplike bends.
4. Did the stream have any branches? Can you be certain from the data? **Answer** It appears that the stream had a tributary entering it from the west-northwest. However, the data in the north-central part of the map is insufficient to be sure. The area near the center may represent an island, or perhaps the stream channel turns toward the north as you go west. This cannot be determined on the basis of the field work either.
5. Make a sketch showing what this sandstone might look like if you could dig a trench five meters deep along one of the gray lines in Figure 16–13. **Answer** Guide Figure 16–2 shows a cross section along A-B. The important point for the students to discover from this cross section is that the stream was relatively deep toward the center and shallow near the shore. The thickness of the sandstone can be used as an approximate index of the depth of the stream.

Suggested additional investigations

Evidence for cross-bedding sometimes can be found in gravel pits. Cross-bedded gravel is most likely to be seen in parts of the country that were glaciated during the ice ages. The direction of flow of the ancient glacial outwash can be established. If you cannot take a field trip to such a place, try to bring photographs to class.

Demonstration A stream table can be used effectively after this investigation. You can build a buried channel in a stream table with outlets at three levels. First, build a delta into a standing body of water at mid-level. Then drain the lake so that the stream will cut deeply into the delta. Finally, flood the delta and part of the incised channel so that a new delta is superimposed over the first. The deep channel will be buried.

For demonstrating stream erosion and deposition on an overhead projector, see *The Science Teacher*, September 1972, page 47.

Answers to thought and discussion

1. How do the characteristics of sedimentary rocks help you determine the environmental conditions under which they formed? Give specific examples. **Answer** Examples may range widely. Fossils and mineral composition are two you should expect. Uniformitarianism is the underlying principle to look for in the answers. Any answer is acceptable that indicates there are objective ways to determine past environmental conditions.
2. Discuss the statement: all layered rocks are sedimentary, and all sedimentary rocks are layered. **Answer** All layered rocks are *not* sedimentary. A lava flow is the best example of layered rock that is not sedimentary. Some metamorphic rocks may appear to have layers, as well. However, all sedimentary rocks are layered, even if you can't see the layers easily.
3. Describe several ways of determining which is the upper surface of a sedimentary layer. **Answer** Ripple marks and mud cracks can be analysed and compared with modern ones. Fossil shells that look like clams usually are deposited with the open side down. Particles in a layer are often graded by size.
4. Where would you expect to find the most coarse-grained texture in an igneous intrusion?

Why? **Answer** In the center of the intrusion. There the material would be well insulated. Larger crystals can form when rock cools slowly.

16–5
Investigating puzzles in the earth's crust

Advance preparation

You can use the master provided in the back of this Guide to prepare copies of Figure 16–17. Make enough to give each student two, a work sheet and a spare.

Time requirements

Pre-lab	5–10 minutes
Lab	20–30 minutes
Post-lab	15 minutes

Materials

The following materials will be needed for each student:

Rock outcrop diagrams in Text
Plastic replica fossils from Basic Fossil Kit
Real fossils (optional)

Pre-lab discussion

Ask students how they could correlate rock outcrops found in widely separated areas. How might they use fossils to correlate rock units? If you have the Basic Fossil Kits, allow students time to become familiar with the appearance of the fossils. Remind students that the numbers in the outcrop diagrams indicate which fossils are found in each layer. For example, the trilobite *Phacops* (#16) is found in any rock layer that is labeled 16.

Notes on procedure

You may want to let students compare several rock units together in class. You could assign the correlation of the other rock units as homework. When you discuss the results, allow students time to express their own ideas of correlating the rock layers. The discussions may become very involved, and individual interpretations probably will vary. This also happens when field geologists correlate rock layers.

Range of results

See the following page.

Post-lab discussion

Use the chalkboard or an overhead projector to discuss the sequence. Have several students put their results on the board. When students have discussed these layers, ask them to describe the history of each outcrop.

Answers to questions

1. Which of the fossils appeared first? How do you know? **Answer** *Michelinoceras* (#9) and *Flexicalymene* (#16) appeared first because they are found below all of the other layers in the diagram. There is no case where a rock layer is found below these two.
2. Which of the fossils appeared most recently? How do you know? **Answer** The *Equus* tooth (#5), because none of the other rock layers ever occur above it.
3. What reason can be given to explain why layers 7 and 12 can be found under 18 and also under 1, but not under the combination of 1 and 18? **Answer** The presence of an erosional surface indicates that they may have been there but were eroded away.
4. Notice that some fossils such as 10 and 16 can be found together only in some cases. Try to give a reason why. **Answer** It is possible that some of the fossils could have lived in environments where others could not. However, under certain conditions, they both could exist in the same environment.

Suggested additional investigations

To vary this investigation for your class you could sketch the fossil zones on photographs of actual outcrops. Use the photographs instead of the block diagrams. The sequence of zones is more important here than the veracity of the photographs.

Another way to set up the investigation is to make "geologic columns" or "core samples" out of strips of paper. Place the numbers of the fossils, pictures of the fossils, or the fossils themselves on the column in the proper sequences. Place the columns around the room to simulate outcrops. Have the students visit the outcrops to gather data.

You could insert some unidentified fossils into the column. You also could invert a column. If you do this, warn students that the layers may have been disturbed.

Solution to the fossil puzzle

The following outline represents a series of logical deductions you can follow. It leads to one possible interpretation of the relative ages of the rock layers. On the outline, 9/15 means that fossil #9 is younger than fossil #15. The rock layers appear in order on the diagram in Guide Figure 16–3.

Step A) 5/2 & 20; 5/8; 5/18; 18/11; etc. Therefore *5 is youngest.*

Step B) 2 & 20/14 & 19; 2 & 20/13; 13/1 & 18; 18/7; etc. Therefore 20 *and* 2 *are second youngest.*

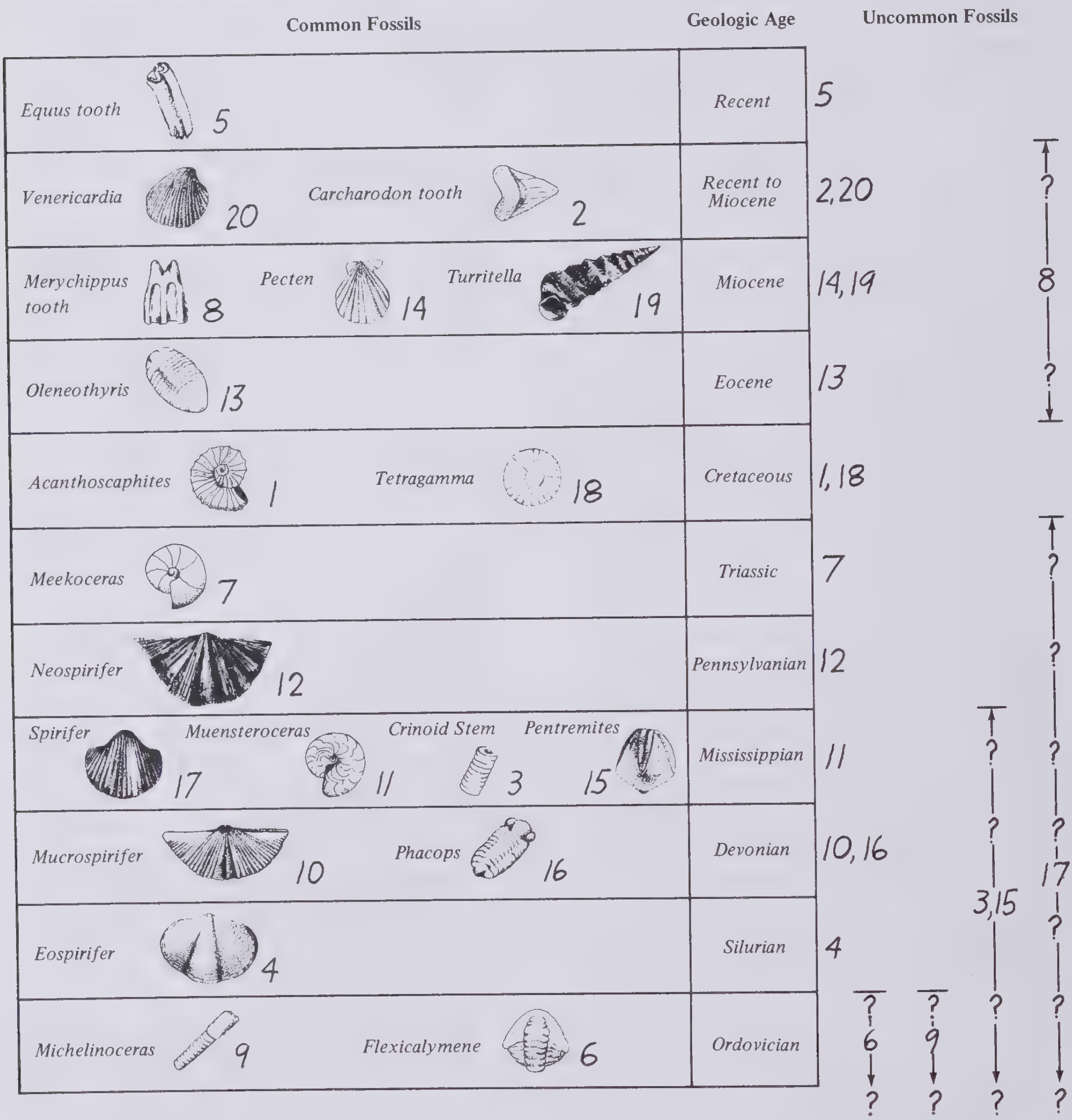
Step C) 5/8; 8/1; 8/7; 8/16; etc. Therefore, *8 can be placed somewhere between 5 and 1 & 18.*

Step D 14 & 19/13; 13/1 & 18; 1/7; etc. Therefore, *14 & 19 are third youngest.*

Step E) 13/1 & 18; 1 & 18/17; 1/7; etc. Therefore, *13 is fourth youngest.*

Step F) 1/7; 1 & 18 are found together; 1 & 18/17; etc. Therefore, *1 & 18 are fifth youngest.*

Guide Figure 16–3
Solution to the fossil puzzle in Investigation 16–5.



Step G) 1 & 18/17; no further data on 17. Therefore, *17 is somewhere between 1 & 18.*

Step H) 1/7; 7/12; 12/11; etc. Therefore, *7 is sixth youngest.*

Step I) 12/11; 7/12; etc. Therefore, *12 is seventh youngest.*

Step J) 12/3 & 15; no further data on 3 & 15. Therefore, *3 & 15 are somewhere below 12.*

Step K) 11/10 & 16/ 10/4. Therefore, *11 is eighth youngest.*

Step L) 10/4; 10 & 16 are found together. Therefore, *10 & 16 are ninth youngest.*

Step M) 4/9; 4/6. Therefore, *4 is tenth youngest.*

Step N) Therefore, *9 (and/or 6) is oldest.*

16–6
Correlating rock layers

Correlation is the matching of isolated parts of the geologic record to give a composite picture of earth history. For students to correlate rock layers, they must apply the basic principles of superposition, original horizontality, and continuity. You might review these ideas before you continue discussing the chapter.

Why are correlations based on rock types or on a particular set of fossils, and not on dates in time? It is rarely possible to correlate rock units in terms of measured time. Radiometric dating of rocks is not yet precise enough to use to solve correlation problems.

In Figure 16–16 thick layers alternate with groups of thin layers. This pattern should give a basis for correlation across the canyon even if the middle part of the photograph were missing. Ask students to correlate layers in the foreground with any layers in the background of the photograph.

Discuss with students the correlation in Figure 16–17. Then ask what might have happened if a layer of basalt had been on top of the conglomerate in location A. The geologist might have thought that the conglomerate in location A was the same conglomerate layer as the one in location D.

It does seem reasonable to conclude that the red sandstone thins out because black and green shale are still in normal sequence. From the available data the geologist cannot pinpoint exactly where the red sandstone ends. The geologist might have confirmed his correlation of the rock layers by matching fossil types.

16–7
Outcrops reveal a sequence of events.

This section gives students an opportunity to solve more sophisticated geologic problems. To analyze the geologic relationships students will have to think back to earlier chapters dealing with rock-forming processes.

Prepare an overhead transparency of Figure 16–19 if you can. In the left diagram, students can infer that molten basalt intruded into two previously existing limestone layers. As the hot liquid flowed between the limestone layers, it gathered fragments of limestone from both above and below. The heat baked and metamorphosed the limestone near the basalt. Students may add that, as heat flowed into the cooler limestone, the edges of the molten basalt solidified rapidly. Crystals in this area are fine-grained. The inner part of the intrusion solidified more slowly. There, it would be relatively coarse-grained. Small tongues of molten rock were forced into cracks in the adjacent limestone. This intrusion is younger than both the limestone layers.

In the right diagram, students can infer that the lava flowed over the top of the limestone. Its heat metamorphosed the top surface of the layer beneath. Fragments of limestone were picked up by the lava. Later, a second limestone layer was deposited on top of the volcanic flow rock. During deposition of the limestone, fragments of the underlying rock were incorporated into the limestone.

The uppermost shale and sandstone must be younger than the lava flow. They are above it in a depositional sequence that seems to be normal. It is not possible to say if the uppermost shale and sandstone in the left diagram are older or younger than the intrusion. Some students may have developed other logical interpretations.

Action Assign the interpretation of Figure 16–20 for homework. Then you can use students' interpretations as the basis for class discussion.

Some teachers have had success by turning the activity around: they give the interpretations to the students and ask them to match each description to a cross section.

The following list of proposed sequences for the cross sections is not the only possible correct answer. Students may present a variety of logical interpretations of the geologic history represented in the cross sections.

Cross section A

1. Deposition of conglomerate, shale, limestone, sandstone, shale, sandstone, and shale. The order could be inverted if the folded layers at the bottom of the diagram have been overturned. There is not enough data to determine which order is correct.
2. Folding of layers deposited in Step 1.
3. Erosion, producing an unconformity.
4. Deposition of conglomerate, sandstone, shale, and sandstone on top of old erosional surface.
5. Further erosion of uppermost layer. (In this and all subsequent diagrams there is no way to know whether the sedimentary layers were deposited on land or in a sea, lake, or river.

Cross section B

1. Shale and sandstone deposited.
2. Basalt has intruded into the middle of the shale.
3. All rock so far is folded. Steps 2 and 3 could be reversed.
4. Erosion resulting in an unconformity.
5. Deposition of conglomerate, sandstone, and limestone.
6. Erosion resulting in an unconformity.
7. Deposition of conglomerate, sandstone, shale, and sandstone.
8. Erosion producing the land surface shown.

Cross section C

1. Deposition of shale in Devonian and limestone in Mississippian.
2. Erosion. Pennsylvanian, Permian, Triassic, and Jurassic rocks missing.
3. Deposition of conglomerate, shale, and sandstone in the Cretaceous.
4. Folding of the whole sequence.
5. Intrusion of granite. The intrusion of granite could have come before the folding and the deposition of all units above the lowermost shale.
6. Erosion. The granite could have been intruded after erosion of the uppermost sandstone and shale began.

Cross section D

1. Deposition of sandstone and shale in the Cambrian.
2. Erosion or nondeposition. Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian rocks missing.
3. Deposition of Permian sandstone and shale.
4. Extrusion of Permian lava, which baked underlying shale.
5. Erosion. Entire Mesozoic layer missing.
6. Tertiary limestone deposited.
7. Folding of whole sequence.
8. Erosion, shown by irregular surface on top of Tertiary and by the unconformity.
9. Deposition of Recent conglomerate, sandstone, and shale.
10. Erosion of modern surface.

Cross section E

1. Deposition of shale, sandstone, shale, sandstone, and shale.
2. Folding.
3. Erosion resulting in angular unconformity.
4. Deposition of limestone and shale.
5. Possible faulting of sequence. The lower right-hand side of the block was moved up relative to the left-hand side.
6. Erosion, shown by erosion surface on top of last horizontal shale.
7. Deposition of conglomerate, shale, and sandstone.
8. Erosion forming present land surface.
9. Intrusion of large mass of basaltic rock. One conduit up from the mass of magma reached the surface and formed a volcano.

Cross section F

1. Deposition of Cambrian shale, then sandstone. In this diagram, tightly folded older rocks overlie younger rocks that are nearly horizontal. If you mentally unfold the Cambrian rocks, you find that the shale must have originally underlain the sandstone. The oldest rock shown in the cross section is the shale layer inside the folded layer of sandstone.
2. Deposition of Permian limestone.
3. Intrusive body of granitic rock in Permian limestone. Intrusion occurred after deposition of the limestone, sometime between Permian and Recent.

4. Cambrian rocks were folded sometime after deposition. This could have occurred at any time after Step 2. There is no record of events between Steps 1 and 2.
5. Cambrian fold was shoved over the top of relatively flat-lying Permian rock as a result of faulting.
6. Erosion formed present land surface.

16–8
Interpreting a chapter in earth history

Time requirements

Pre-lab	10–15 minutes
Lab	20–40 minutes
Post-lab	10–20 minutes

Materials

The following materials will be needed by each group of two students:

- Modeling clay from Geologic History Kit or other modeling material, 4 colors, ¼ pound each
- Powder, flour, or plastic film
- Knife or cheese cutter
- Wooden roller from Geologic History Kit

Special notes

Make sure students put powder or plastic film between the layers of clay. If they neglect to do this, the layers cannot be separated for reuse.

Pre-lab discussion

Discuss the technique illustrated in Figure 16–21 for putting features into the models. You could build a model or use one from last year and display it to the students. Remind each group to keep a list of the sequence of events in their model.

Notes on procedure

Construction of a simple model is shown in Figure 16–21. Encourage students to put as many processes as they can into their models. You might make the preparation of models a competition to see which model is the most puzzling to interpret. Be sure students always deposit layers horizontally. If deep valleys are eroded into the clay, the next layer must fill in the low spots before it can go on top of the sequence.

When a group thinks it has figured out a proper sequence of events for a model, have the model makers evaluate the answer.

Post-lab discussion

After the models have been exchanged and analyzed, each group should present its results to the students who made the model. There are likely to be some disagreements in these discussions. The interpreters sometimes accuse the model makers of being too sneaky, or of not following the geologic principles correctly. In some instances, there may be two or three interpretations that can be applied equally well to some part of the model. If the group's interpretation fits all of the data, the interpreters cannot be penalized. A geologist interpreting a situation may never be able to determine which possible answer is best.

Answers to questions

1. Which layer is the oldest? How do you know? **Answer** Although the different models will produce different answers, generally speaking, the layer on the bottom of the model will be oldest. One exception will be a bottom layer that represents an igneous intrusion.
2. What are the relative ages of the rest of the layers? **Answer** In a sequence of undisturbed sedimentary layers, the layers decrease in relative age from bottom to top.
3. If your mountain contains folded layers, when did folding occur? Can you determine from the shape of the folds how they were formed? **Answer** Folding occurs *after* the deposition of the youngest folded sedimentary layer and *before* the oldest undeformed layer is deposited. Folds generally run perpendicular to the direction of the pressure that formed them.
4. Is there evidence that any of the layers have been eroded? How do you recognize a former erosion surface? **Answer** It may be difficult for students to produce buried erosional surfaces on the models. Some groups may show erosion by cutting off the tops of folded layers. Some may fill in stream channels with younger sediments. Other ways to indicate

erosion include having thinner sedimentary layers on one side of a fault than on the other, or having exposed younger layers on the inside of an eroded uplift or dome.

5. How would you explain a layer of one color cutting through layers of other colors? **Answer** This probably represents an igneous intrusion. The intruded layer is younger than the surrounding rock layers.
6. Have any layers been disrupted by faults? **Answer** This will depend on the models constructed. Usually several groups in each class attempt to show faulting in their models.

16–9
Clues to ancient climates

Maps like Figure 16–22 are less trustworthy for earlier time periods. Paleontologists are not as sure of their inferences concerning the environments of ancient animals. For example, one cannot be certain that a very distant ancestor of a modern warm water animal also was restricted to a warm water environment. Most of the time, however, it seems reasonable to interpret ancient environments on this kind of information. When salt deposits were forming in Michigan, New York, and Germany, their climates must have been hot and dry for seawater to evaporate. Today all three regions are wet and fairly cool. Salt is not being deposited now.

Answers to thought and discussion

1. How could you recognize a buried erosion surface? **Answer** It would be similar to a modern erosion surface. It would have rock units that appear to have missing pieces. The surface would contain weathered material, and possibly plant remains.
2. How could you tell whether an igneous rock was from a lava flow or an intrusion? **Answer** A lava flow produces no baked zone on the rock that comes to lie above the lava. An intrusion produces baked zones wherever it touches the rock into which it intrudes.
3. What types of evidence about ancient climates are found in rocks? **Answer** Remains of living organisms can be compared with their modern counterparts and the environments in which they live. The minerals present also can serve as indicators of ancient climates.
4. How are fossils used in correlating rocks separated by great distances? **Answer** Rock units separated by great distances can be correlated by recognizing that the same or similar fossil species are found in matching rock layers.

Additional investigation (optional)
Field trip: Investigating earth history in the field

Looking at rocks in the field differs considerably from working with hand specimens and diagrams. If at all possible, plan a field trip similar to one outlined here.

A field trip will enable students to examine and collect rocks and to interpret the geologic record they provide. It is an excellent opportunity for students to transfer skills learned in the classroom to natural situations.

Advance preparation

Obtain permission prior to taking your class onto any private land. Visit the area shortly before the class visit and go over the route of the field trip carefully. Plan how long you want to spend at each outcrop. Know in advance exactly what you expect your students to do at each location.

Prepare several maps of the field trip area. You can trace topographic or geologic maps of the area. Maps and information are also available from your state geological survey or from geology teachers at a local college.

Good background information can be found in *Sources of Earth Science Information*, ESCP Reference Series pamphlet RS-1, and also *Selected Maps and Earth Science Publications*, ESCP Reference Series pamphlet RS-4. The ESCP field guide pamphlets, *Field Guide to Layered Rocks* and *Field Guide to Fossils* will be especially helpful in planning field activities.

Arrange for transportation and obtain parental and administrative permission if the trip is to be held away from the school grounds. Have other teachers, parents, or students from previous

classes go along as assistants. There should be *at least* one leader for every 20 students.

Time requirements

The field trip may last several class periods, a half day, or a full day. The amount of time necessary depends upon the distance you travel and what activities you plan for the students.

Materials

The following materials will be required for each class:

- Hand lenses
- Measuring tapes
- Rock hammers and chisels. (These items may be prohibited in certain public parks.)
- Plastic bottles of *dilute* hydrochloric acid
- Compass
- Maps of the field-trip area
- Rock collecting bags
- Notebook
- First-aid kit
- Safety glasses

Special notes

Be prepared for scratched knees and elbows. A first-aid kit must be available.

If students use hammers, caution them to beware of flying chips. Have students who are hammering wear safety glasses. Nearby students should always turn their heads or shield their eyes.

Many rock exposures will be along roads. Warn students about traffic and keep them off the road at all times. Avoid leaving hunks of rock in ditches at the foot of roadcuts where they will impede drainage.

In quarries or on steep slopes remind students to avoid working directly below someone else. Keep them away from dropoffs.

When you are on private land, close all gates, and keep fence-climbing to a minimum.

Wherever you go have students pick up all litter.

Pre-field trip discussion

Students should know where they are going and why the site was chosen. They should also be told what they are expected to do during the field trip and after they return.

Notes on procedure

If you travel to the field trip area on a bus, the ride can be an important part of the trip. You might brief students at that time. You also could discuss features of geologic interest along the way. If the bus has no public address system use an electric bull horn.

Treat each rock outcrop as a problem in geologic interpretation. Students will observe and ask questions about features you may not fully understand yourself. Answer what questions you can, but do not attempt to be the final authority. Try to stimulate curiosity so that the student may want to study the problem further. Before you leave each outcrop gather the group and review the features observed.

Many kinds of activities are possible on field trips. A few are suggested:

Measuring stratigraphic sections Take students to an area of sedimentary rocks. Before they begin, ask students how they will decide where each layer begins and ends. Suggest that they assign numbers or letters to the rock layers they distinguish. Have students measure the thickness of each layer. If layers in the outcrop are inclined or folded, students should remember to measure the vertical thickness perpendicular to the bedding.

Once students have measured the layers, have them look for various details of sedimentary structures. Are the beds right side up? What environmental and depositional conditions are suggested by the various rock types? Are there fossils? Which layers are oldest? Can any unconformities be seen? Are there faults in the outcrop? Are there folds? In which direction did movement occur?

A good way to encourage students to discover as much as possible is to become one of the discoverers yourself. You probably will find new things each time you visit an outcrop.

Correlation For students to correlate different rock exposures, you must take them to two or more outcrops where the same rocks can be found. Have them measure the second outcrop just as they did the first. Then see if students

can match the units. Also look for fossils, minerals, and other physical features that the two exposures may have in common.

Determining the sequence of events If you visit outcrops containing intrusions, angular unconformities, or other interesting structures, have students work out a sequence as they did in class.

Other activities Further suggestions for suitable field trip activities can be found in most college textbooks of field geology. A professional geologist in your area may have useful suggestions.

Schoolyard field trips If a field trip is impossible, you can set up artificial outcrops in the schoolyard. Ask students to correlate, measure layer thickness, find evidence for folding, and so forth. Your imagination is the only limit to the possibilities for this kind of exercise.

Post-field trip discussion

Be sure to discuss what the class saw on the trip. You might ask students to submit reports of their observations. Post some of the reports on the bulletin board.

Discussion of unsolved problems

Vast amounts of geologic field work combined with careful study of models in the laboratory will have to be done before many of the problems of the earth's history are solved. The modern approach to interpreting earth history is based on the principle of uniformitarianism. It relies on detailed observation of present-day processes in the field and laboratory. Then scientists study features of the rocks themselves to see how they can be related to the modern processes.

We know a great deal about Paleozoic, Mesozoic, and Cenozoic rocks in some parts of the earth. Our knowledge of Precambrian rocks, however, is slight. We know much more about the most recent 13 or 14 per cent of the earth's history than we do about the remainder.

Answers to questions and problems

A

1. In Section 16–2 there are examples of a single layer of sediment varying from one place to another. Describe some other circumstances in which horizontal variation might occur within a body of rock. **Answer** (1) A sudden increase in the velocity of a stream would result in coarser-than-usual sediments. (2) Gradations could be caused by currents flowing parallel to the shorelines of seas and lakes. (3) Pools or lakes along stream channels would accumulate finer-grained sediments. (4) Materials picked up by streams in different areas may have varied densities. When these particles are deposited in another area they may be smaller or larger than the usual size.
2. How would you explain a graded bed with large grains on top and smaller grains on the bottom? **Answer** (1) The bed may have been turned upside down by folding. (2) The finer particles may be more dense than the coarser particles. (3) Regional uplift may have been taking place, causing the velocity of the stream to increase gradually, and coarser particles to settle on top of finer particles. Uplift usually would be so slow that grading would not be found within a single bed. Instead, there would be a fine-grained bed at the bottom of the pile and progressively coarser-grained beds higher up the pile. Each bed would be relatively homogeneous.
3. How could a sandstone form that is composed almost entirely of well-rounded sand grains? **Answer** (1) It could be derived from a previous sedimentary rock with well-rounded (or partly-rounded) quartz in it. (2) It could be formed from sand that had been carried from a very distant source. Students may suggest other possible explanations.
4. What features do sedimentary rocks have that igneous and metamorphic rocks don't? **Answer** Distinguishing features of sedimentary rocks are well-developed layering, fragmental textures, ripple marks, mud cracks, graded bedding, cross-bedding, and many others. None of these features, however, belongs exclusively to sedimentary rocks.
5. Suppose you find two sedimentary rocks. One of these, composed of rounded fragments of calcite, is relatively soft. The other rock, composed of fairly angular fragments of quartz, is

relatively hard. Can you say whether the calcite grains have been transported farther than the quartz grains? **Answer** You cannot say much about the relative distance of transport of the two kinds of grains. Calcite is more easily rounded than quartz, so calcite rounding is not an indicator of great transport distance.

B

1. Under what conditions might sediments not be horizontal at the time of deposition? **Answer** Original beds might not be horizontal if sediments were deposited around a hill, reef, or any abrupt irregularity on the surface. As the pile of sediments grows deeper, it should gradually become horizontal. Deposits in alluvial fans, where streams are flowing out of a mountain valley, also may be inclined.
2. Are the interfaces between sedimentary layers always distinct and abrupt? Explain your answer. **Answer** No. For distinct, abrupt bedding planes to form, deposition usually ceases. A new episode of deposition follows, perhaps after a period of erosion. Material from one source may suddenly stop coming into the depositional basin just before material from a different source floods into it. This will produce a fairly abrupt transition from one kind of sedimentary rock to another. Any rapid change in conditions might produce bedding planes. For example, if there were a flood in a stream, coarse particles might be dropped on top of fine-grained sediments.
3. Would you expect to find horizontal variation in igneous and metamorphic rocks? **Answer** You can expect to find horizontal variations in any rocks, including lava flows and granites. The variations may be in texture, structure, or composition of the rocks.
4. Quartz is probably the most common mineral in sandstones throughout the world. Yet on many beaches in Florida most sand grains are composed of calcite. Suggest reasons for this situation. **Answer** Sand on beaches in Florida and on some oceanic islands is made mostly of calcite (mainly shell fragments) because there simply was no quartz around. The black and green sands of Hawaii are not quartz, either. They are composed of basalt and olivine.
5. Some rocks consist entirely of volcanic ash and fragments of rock that have fallen into a pile at the foot of a volcano. Would rock formed from this material be sedimentary or igneous? **Answer** You can call this rock either igneous or sedimentary. It is certainly igneous in origin, but it has been deposited through a fluid—the air—like a sedimentary rock. This borderline case emphasizes that our system for rock naming is artificial.

C

1. Suggest a way that cross-beds might form from ripples in sand on the bottom of a sedimentary basin. **Answer** Ripple marks migrate along the bottom of bodies of water. If small asymmetrical ripples migrate over the backs of larger asymmetrical ripples, they fall over the edge of the larger ripples. When they do so, a thin layer of sediment accumulates at an angle to the regular bedding direction.
2. Suppose you find a rock composed of 50 per cent fragments and 50 per cent crystalline cement. Would you call it fragmental or crystalline? **Answer** You can call this rock either crystalline or fragmental. Continuous gradations exist between completely fragmental and completely crystalline sedimentary rocks. This happens to be a borderline case.

Supplementary Materials

REFERENCE BOOKS

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Stokes, William L. *Essentials of Earth History: An Introduction to Historical Geology*, 3rd ed. Prentice-Hall, Inc., Englewood Cliffs, N.J., 1973.

FILMS

Rocks That Form on the Earth's Surface. 16 minutes, color. American Geological Institute-Encyclopaedia Britannica Educational Corp.

Erosion — Leveling the Land. 14 minutes, color. AGI-EBEC.

The Petrified River — The Story of Uranium. 28 minutes, U.S. Bureau of Mines.

Why Do We Still Have Mountains? 20 minutes, color. AGI-EBEC.

Story In the Rocks. 18 minutes, color. Shell Oil Company.

Reflections on Time. 18 minutes, color. AGI-EBEC.

17. Life: Present, Past, and Future

Chapter Objectives

After completing this chapter, students should be able to:

1. Identify three criteria to distinguish a living organism from a nonliving object.
2. Discuss some of the ways organisms receive, use, and store energy.
3. Give examples tracing the circulation of water and carbon from the nonliving world to the biosphere and back.
4. Determine how a fossil was preserved after examining it.
5. Describe briefly the changes in one plant or animal shown by the fossil record.
6. Describe how fossils give clues to the climate, geological events, and changes of life forms in earth history.
7. Demonstrate the geometrical increase of numbers associated with population growth.
8. Give several examples of how the study of earth science may help solve environmental problems.

Teaching the Chapter

The major theme of this chapter is that living organisms on earth, as well as rocks and minerals, have changed through time. Students discover that most of these changes can be explained best by theories of organic evolution. Students begin by working out a definition of life. Then they practice applying to the fossil record what they know about life today. This chapter thus continues developing the concept of uniformitarianism introduced in Chapter 16.

Students relate events in the physical history of the earth to the biosphere. They investigate the fossil evidence of prehistoric organisms. In an investigation students make simulated fossils and practice interpreting them.

Let the sections on paleontology give an overview of the order and speed in which different groups of organisms developed. Students use this time perspective when they investigate a model of the world population growth rate. They also apply this perspective to current problems of pollution.

Suggested time required

About six to eight days will be required to complete the investigations and discuss the topics in this chapter.

Section Notes

17–1
What is life?

The purpose of this section is to sharpen students' intuitive definition of life. One way to begin is to gather about two dozen photographs. About half should show a living organism. The rest should feature nonliving items. Show the photos to the class. Ask students whether each photograph is of a living thing or a nonliving thing. Try to include some pictures where the choice will be difficult. Lichen on a rock, for instance, is living, although many students will notice only the rock in a photograph.

After students have sorted the photographs, ask what characteristics the living things have in common. Do nonliving objects ever show those characteristics? Is there any single characteristic that always separates living and nonliving things? Students usually conclude that although nonliving things may show some of the characteristics of living things, they never show all of them at once. How could you find out if an object were alive?

Demonstration Place a petri dish containing 10 per cent nitric acid and a drop of mercury on the stage of the overhead projector. Do not tell students what chemicals are being used. Wait until the mercury is still. Ask if the dark object is alive. The answer should be "No." Sprinkle a little potassium dichromate ($K_2Cr_2O_7$) on the nitric acid. The mercury will react with the potassium dichromate and move about the petri dish, looking as if it were alive. After a moment or two, ask again if the dark object is alive.

Action Center the discussion around a live animal and plant in the classroom if you can.

1. What differences between the frog and the rock in Figure 17–1 determine which is alive? **Answer** Student responses will vary. Most answers will indicate that the frog responds to outside stimulation differently from the rock. Also, the frog is able to move by itself. The rock moves only if an external force is applied.
2. How are the plant and frog similar? How are they different? **Answer** Similarities: (1) Both are living material and (2) both store energy. Differences: (1) Plants typically are supported by cell walls; animals are not. (2) Plants generally are unable to move from place to place by themselves as animals can. Many answers are possible.
3. How are the plant and the rock similar? How are they different? **Answer** Similarities: (1) Both are composed of chemical compounds and (2) lack autonomous movement. Differences: Plants can (1) grow, (2) reproduce, and (3) respond to outside stimulation.
4. Was the rock ever alive? Could the rock show any evidence of life? **Answer** Some students will say you cannot tell whether it was once alive. Others will point out that if you know the rock's chemical composition, you can make assumptions about its origin. The rock could show evidence of life if it contained a fossil.

After the discussions in this section students should conclude that it is very hard to give a good definition of life. About the best you can do is to say that living things are composed of carbon compounds and can grow, reproduce, and respond to outside stimulation. Nonliving materials, however, may be composed of carbon compounds and they may also grow, reproduce, and respond to outside stimulation. They will not, however, be able to do *all* of these things.

You might mention the problem of deciding whether viruses are alive or not. Sometimes viruses reproduce the way other living things do, but at other times viruses become crystalline — like sugar.

17–2
Life and energy cannot be separated.
17–3
Organisms and chemical cycles

It is important for students to understand that *all* life is powered by sunlight. You might discuss how food chains transfer the sun's energy to animals and non-green plants. These organisms, including man, cannot use energy directly from the sun.

Show students on the chalkboard that the reaction shown in the equation for photosynthesis works from right to left as well. When you turn the arrow around, the equation shows that plants and animals burn carbohydrates with oxygen. This produces the energy that enables them to do work, plus some carbon dioxide and water. They don't need chlorophyll to do this.

Section 17–3 discusses some other biological processes that transfer chemical elements between the inorganic world and the biosphere.

Answers to thought and discussion

1. Where do organisms get their energy? **Answer** Plants and animals get their energy from the sun. Green plants convert light energy to food by means of photosynthesis. Animals eat the green plants, and convert the energy stored in plant material into energy for their own use.
2. Give your own definition of life. **Answer** Life is not easy to define. The difference between a lizard and a rock is obvious, but it is often very difficult to separate the simplest organisms from the most complex nonliving matter. In general, however, life has been defined on the basis of its (1) organic composition, (2) growth, (3) ability to reproduce its own kind, and (4) response to outside stimulation.

Some students may reach other conclusions.

3. Can you explain the statement: Coal is "petrified sunshine"? **Answer** Since coal is formed from organic matter, students' answers should focus on the solar energy that was trapped in the plants that later were converted to coal.
4. Explain how the idea of cycles is useful in relating natural processes. **Answer** Cycles keep chemical substances in constant circulation between the biosphere, atmosphere, hydrosphere, and lithosphere. Some materials don't get used up because this cycling replenishes the supply.

17–4
Fossil evidence of prehistoric organisms

You can point out how this section relates to Chapter 16, The Record in the Rocks. Fossils and the physical nature of the rocks in which they are found are used to unravel earth's history. Subsequent sections detail how to use fossils to study past environments and ancient life. At this point in the chapter it is sufficient to touch lightly on these topics. They will be refreshed later. This is also a good place to review the principle of uniformitarianism.

When first used, the term *fossil* was applied to almost any ancient object dug out of the ground. It included rocks, minerals, and archeologic objects, as well as fossil remains. Modern usage, however, decrees that the term be applied only to the traces or remains of prehistoric plants and animals.

There are several reasons why most fossils are found in marine sedimentary rocks. Life existed in the sea long before it did on land. Life always has been more abundant in the sea than on the land. Burial in marine sediments, such as mud and sand tends to promote preservation. In fresh water sedimentation is not so widespread. Consequently, the fossilized remains of freshwater organisms are not as abundant as fossils of marine origin. Plant fossils are relatively rare, mostly because their hard parts are fragile.

Action If any students have fossil collections, encourage them to bring the collections to class. The ESCP pamphlet *Field Guide to Fossils* will help students organize and study their fossils.

17–5
Investigating a footprint puzzle

Advance preparation

Make an overhead transparency of the footprint puzzle from the master provided in the Guide. Have a blank piece of paper on hand to mask the puzzle when it's on the projector.

Time requirements

Pre-lab	5 minutes
Lab	30 minutes
Post-lab	10 minutes

Pre-lab discussion

Simply point out to the students that they will be attempting to reconstruct happenings from the geologic past. In this investigation students will form several defensible hypotheses. As more evidence becomes available the hypotheses must be modified or abandoned.

Notes on procedure

Use a blank piece of paper to slide across the transparency and reveal additional puzzle sections. Begin by projecting the first part of Guide Figure 17–1. Be receptive to any reasonable hypotheses students offer to explain the footprints. As you show the next section of the transparency students will see that the first hypotheses need to be modified and new ones probably can be added.

Next project the complete puzzle and ask students to interpret what happened. A key point for students to recognize is that the conclusion must be based only on those tentative hypotheses that still apply when all of the puzzle is projected. Any interpretation that is consistent with all the evidence is acceptable.

Should it become necessary to prod the students' thinking and stimulate the discussion, the questions below may help. Students should give evidence for their answers.

1. In what directions did the animals move?
2. Did they change their speed and direction?
3. What might have changed the footprint pattern?
4. Was the land level or irregular?
5. Was the soil moist or dry on the day these tracks were made?
6. In what kind of rock were the prints made?

7. Were the sediments coarse or fine where the tracks were made?

The environment of the track area should also be discussed. If dinosaurs made the tracks, the climate probably was warm and humid. If students propose that some sort of obstruction prevented the animals from seeing each other, this might suggest vegetation. Or, perhaps the widened pace might suggest a slope. Speculate on the condition of the surface at the time the prints were made. What conditions were necessary for their preservation?

Range of results

An imaginative student should develop several defensible hypotheses. One of the most common is that two animals met and fought. There is no real reason to assume that one animal attacked and ate the other. Certain lines of evidence — the quickened gaits, circular pattern, and disappearance of one set of tracks — do seem to bear this out. It might, however, have been a mother picking up her baby. Many explanations are possible. The description and temperament of the animals involved are open to question. Indeed, we lack the evidence to say that the tracks were made at the same time. The intermingling shown in Guide Figure 17–1 may be evidence that both tracks were made at one time, but it could be only a coincidence. Perhaps one animal passed by and flew off, and then the other came along. We still cannot say.

Suggested additional investigations

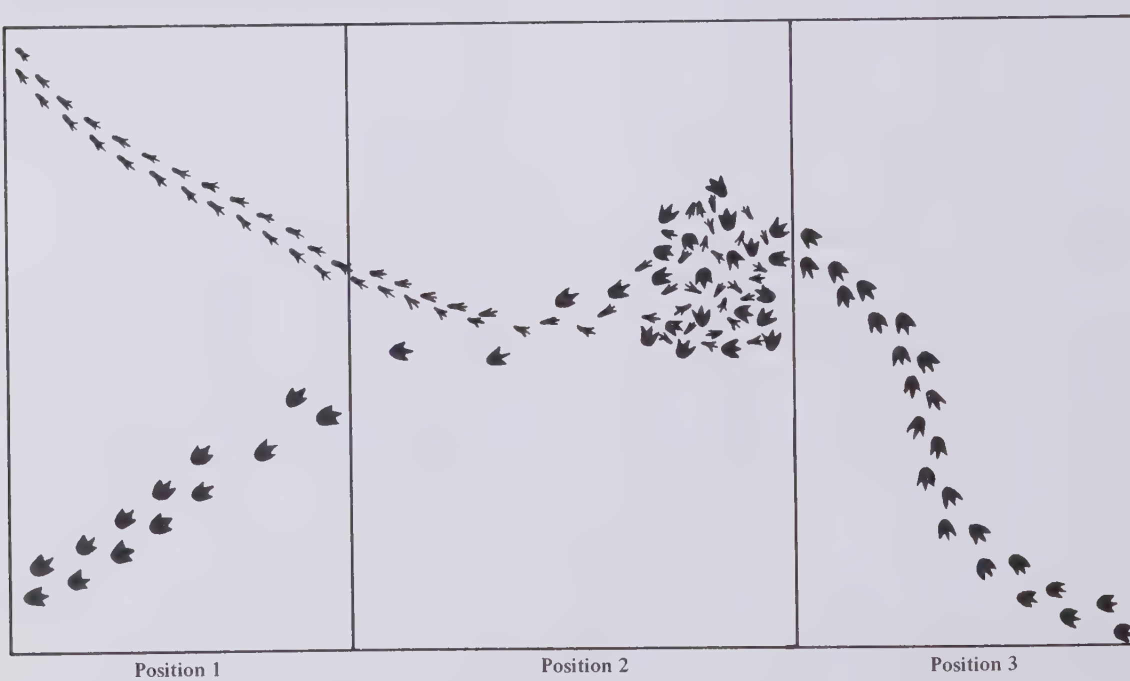
You can have more discussions on interpreting series of events using animal prints students find out-of-doors and reproduce for the class. Don't forget to look for human footprints.

17–6
How fossils form

You might precede class discussion with one of the filmstrips on fossils listed in Supplementary Materials. Then you could discuss the basic requirements of fossilization. What factors might prevent the preservation of organic remains? You might ask students why fossils are seldom found in igneous rocks. Molten igneous material such as lava normally destroys organic matter on contact. Animals usually desert an area where volcanic activity is taking place. We assume this is the reason that no fossilized animal remains have been found in the volcanic ash and dust that buried the fossil forests at Yellowstone National Park.

You could ask students to compare the condition of the Berezovka mammoth to meat stored in modern freezers. Ask students what happens if food is removed from a home freezer and al-

Guide Figure 17–1
Entire footprint puzzle for Investigation 17–5.



lowed to thaw and remain in open air. Compare the appearance of meat frozen without a wrap to meat sealed in plastic. Which would more likely become a fossil?

Insects in amber are still available from some fossil supply houses. Display a specimen if you can.

Have students suggest areas where drying out (desiccation) might create natural mummies today. Caves and sand deposits in arid and semiarid areas are likely places for this type of preservation.

Scientists believe that the accumulation of bones at La Brea represents the remains of Pleistocene herbivorous animals that became mired in the tar while seeking water, and carnivorous animals that had been seeking food. This theory seems to have validity since some modern tar pits are commonly covered with water. Unsuspecting animals sometimes become trapped in the tarry layer beneath. The film *Prehistoric Animals of the Tar Pits* (listed in Supplementary Materials) describes the process.

Demonstration A common type of fossilization results when the hard parts of an organism have additional minerals deposited in their pore spaces. This process is known as *permineralization.* Permineralization can be demonstrated with a common cellulose sponge (a brightly colored one is best) and some paraffin. Melt the paraffin and saturate the sponge with it. Allow the paraffin to harden and examine the sponge. Cut it into pieces to see inside.

The paraffin in the voids in the sponge has made it more resistant to physical and chemical change. The paraffin is analogous to the minerals deposited by ground water when permineralization occurs.

Demonstration *Carbonization* is another common type of fossilization, especially for plant remains. Even the most delicate structures are recorded in considerable detail by the thin films of carbon. Artificial carbon imprints of leaves can be prepared as follows: Embed a large leaf in about an inch of cement in a disposable plate. Let the cement dry. Bake it in a hot oven for two hours. Break it open with a sharp blow on the thin edge of the cement. A carbonized impression will be visible. If you have a demonstration collection of fossils, compare the artificial carbon imprint with a natural carbon impression. How do these differ from or resemble each other? Which of them more closely resembles a leaf?

17–7
Investigating casts and molds

Advance preparation

If you choose to have students make the molds and casts at home, prepare a small bag of plaster for each student. Distribute the bags a day or two before you want to do the post-lab activities in class.

Time requirements

The investigation should take one-half period if students do the plaster work at home. It will take about 1½ periods if the entire investigation is done in class.

Materials

The following materials will be needed for each student or group of two:

- Fast-drying plaster, 1 lb.
- Container for mixing
- Food coloring (optional)
- Stirring device
- Aluminum pie plate or milk carton
- Objects to cast
- Petroleum jelly or non-detergent soap solution

Special notes

Be sure to use fast-drying plaster, not ordinary wall plaster.

Remind students to add plaster to water, not vice versa.

Clean mixing containers before the plaster sets. Do not pour plaster down a drain.

Pre-lab discussion

Go over with the class the procedure for making the molds and casts. Encourage students to cast common objects in uncommon views, as well as a few less common objects.

Notes on procedure

If you elect to make casts and molds during class, mix one or two large batches of plaster, then go around and fill the aluminum plate of each student. You also can save time by having your

second class make casts on the molds made by your first class. Then the second class makes its own set of molds.

Range of results

Every object will not produce a perfect mold. A common problem is bubbles in the plaster. Too much petroleum jelly on the object may obscure details in the mold or cast. Expect some broken casts.

Post-lab discussion

Have students exchange completed molds. After a few minutes ask students to interpret the mold they examined. Other students should be ready to question dubious interpretations. Repeat the procedure with casts.

Emphasize the interpretive part of this investigation rather than the mechanics of making casts and molds. The most important part of the exercise is examining and interpreting imprints of objects. From this, students should be able to recognize some of the difficulties a paleontologist encounters in dealing with fossil materials that are commonly incomplete.

17–8
Fossils are clues to earth history.

This section reinforces some of the concepts developed in Chapter 16. Review the use of fossils in indicating climate and in correlating layers of rock. Point out that the best guide fossils are the remains of organisms that did not live long in geologic history but were geographically widespread.

Make a transparency of Figure 17–20. Use it when you discuss how life has changed through time. You can use the same transparency again when you discuss the theory of evolution in Section 17–9.

You might be able to arrange a field trip in conjunction with this section. Oil companies and mining operations often offer trips to laboratories or field sites as a public service. They also may be willing to show the actual operation of correlation.

Parts of the filmstrip set *An Introduction to Fossils* or the film *Parade of Life* would be good to show at this time. (See Supplementary Materials.)

Answers to thought and discussion

1. Why are soft-bodied animals such as jellyfish seldom fossilized? **Answer** They lack the hard parts that normally are necessary for an organism to become fossilized. The soft parts decompose too quickly.
2. Name some materials that have been known to replace organic matter. **Answer** Compounds of silica, iron, magnesium, or calcium commonly replace the hard parts of organisms. The soft tissues normally are not replaced, but decompose.
3. How are fossils useful to man? **Answer** Fossils are put to scientific use as clues to past climates, geographic conditions, and life forms. Certain fossils are useful in the search for geologic formations that may contain valuable deposits of coal, ore, or petroleum.

17–9
Plants and animals change through time.

Prepare an exhibit of fossils to accompany the discussion of this section. You may use actual fossils or plastic models from the Basic Fossils Kit.

An interesting discussion topic is the way creatures become adapted to changing environments. Which animal do your students think is more likely to become extinct, rats or tigers? What reasons do they give for their choice?

Excellent background material can be found in Ruth Moore's book *Evolution* and in the *Scientific American Offprints* ("Darwin's Finches" and "Darwin's Missing Evidence") listed in the Supplementary Materials. The BSCS biology textbooks are also good reference sources. The Life filmstrips *The Galápagos Islands* and *Evolution Today* are suitable for use with this section.

17–10
Investigating variation and evolution

Advance preparation

Students may use either a frequency distribution graph or scattergrams to graph their results. You may wish to make an overhead transparency of each to illustrate how they are constructed and to show the differences between them.

Time requirements

Pre-lab	10 minutes
Lab	25–30 minutes
Post-lab	10–15 minutes

Materials

The following materials will be needed by each group of three students:

- Molded plastic fossil sheets #1 and #2 from Variation and Evolution Kit
- Caliper from Variation and Evolution Kit
- Metric ruler
- Masking tape, one roll per class

Pre-lab discussion

Pass out one of the fossil sheets. Ask students to look at the sheet and describe the fossils they see. List all of their responses on the board. Some terms will be very poetic, such as "like butterflies." Others will be more objective, such as "triangular with slanting ribs." Do not edit the descriptive terms. All of the offerings are very useful in discussion.

Hold a fossil sheet in front of the class and ask them to point to one that "looks like a butterfly." They probably will not all point to the same fossil. While the "butterfly" description is correct, it is not useful in distinguishing one fossil from another. As the discussion continues students should conclude that quantitative descriptions of specific characteristics, such as length, width, and number of ribs, are the most useful.

Notes on procedure

Distribute plastic fossil sheets, making sure that each group has two different sheets. Each student measures the length, width, or number of ribs of each fossil on one of the sheets. Then students exchange data with the others in their group to get the measurements from the other sheet.

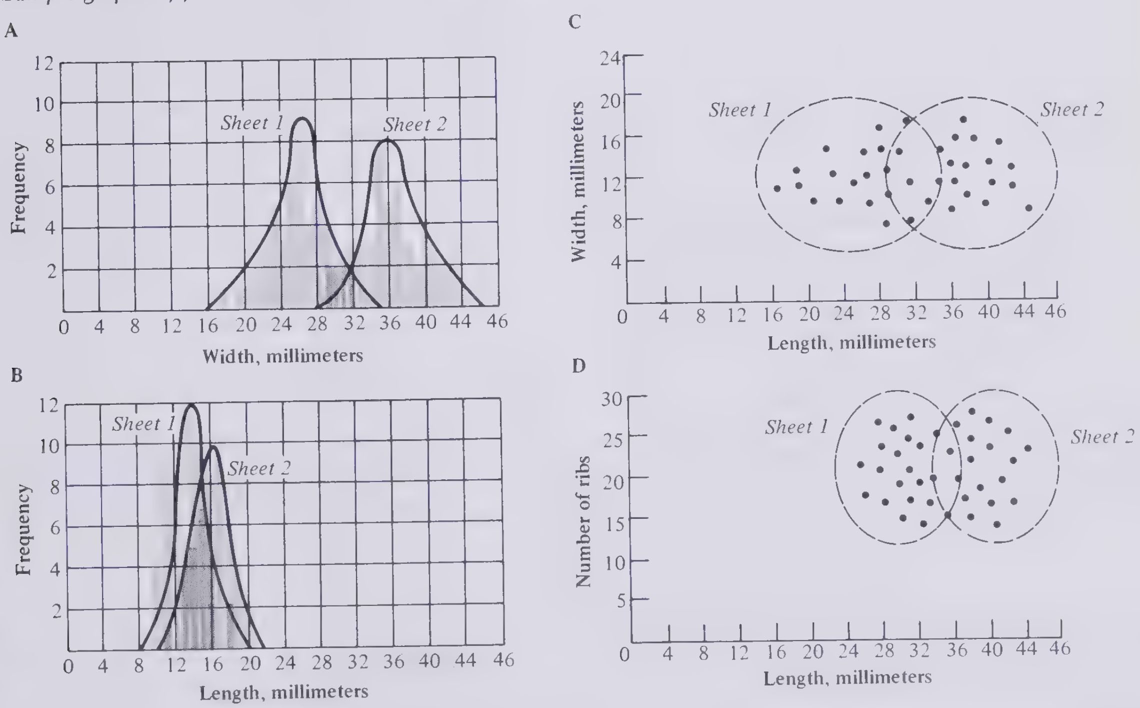
You might suggest that students stick a short strip of tape to each fossil after it is measured. This will help prevent remeasuring the same fossil.

Students make either a frequency distribution graph or a scattergram of the data. They should plot one measurable feature against another. Or they may graph the measurements of a feature against the number of times that particular measurement occurs.

Range of results

Typical student results are shown in Guide Figure 17–2. How well the fossil populations separate into two groups depends on the scale of the graph. If students expand the scale of the frequency distribution or scattergram the differ-

Guide Figure 17–2
Sample graphs of fossil characteristics for Investigation 17–10.



ences of the two fossil populations become more obvious.

POST-LAB DISCUSSION

Display the graphs showing frequency distribution according to length and width. Graphs from either fossil sheet will rise toward some mean without great irregularities. These curves represent a continuous normal variation. Students can estimate what the characteristics of an average fossil from each group would be.

Since the mean for the graphs from the two sheets is not the same, students may ask if they are dealing with different kinds of fossils. They may ask if the difference is caused by evolution, variation, or some other factor. This question cannot be answered with the available information but should lead to a lively discussion. The scattergrams can be used to support the results of the frequency curves. By themselves the scattergrams will indicate the differences that exist between the groups of fossils.

Answers to questions

1. How do the fossils on each slab vary? **Answer** Individual fossils on each slab vary in a smooth curve about the mean of some measurable feature. Students might express this by saying that most of the fossils cluster about some average size. Only a few are much larger or smaller.
2. What similarities are apparent in each population? What differences exist? **Answer** Each population has the same type of distribution since the graphs of both slabs are similar. Each population clusters about a different mean.
3. What evolutionary trends might be exhibited? **Answer** The fact that the two samples have a different mean may or may not indicate evolution. The sample is too small to be reliable. The difference might mean that the two populations represent different species. They might be the same species, but one population came from a climate more favorable to growth.

Suggested additional investigations

Have students collect snails, seashells, or local fossils and measure the variation among similar individuals. You might collect a bucketful of one kind of shell and have the class make a frequency curve of some characteristic.

Another procedure might be to plot the number of ribs on one axis of the graph, and shell width or length on the other axis. This procedure results in a scattering of points on the graph.

17–11
The evolution of the horse

The evolution of the horse is one of the classic studies in evolutionary change. More detail is given in George Gaylord Simpson's book *Horses* and in most historical geology textbooks. (See Supplementary Materials.) These books have charts on which you can base overhead transparencies. You can also use Figure 17–18 for this purpose.

Answers to thought and discussion

1. How does the theory of evolution relate to paleontology? **Answer** The theory of evolution can be used to explain the changes that have taken place in organisms through geologic time. These changes also can be used as evidence that evolution has taken place. Is this reasoning circular? An argument frequently raised in opposition to the theory is that the reasoning is circular.
2. How did Darwin explain the process of natural selection? **Answer** Darwin's explanation was that the individuals best suited to their natural surroundings were the ones most likely to survive. These individuals would pass the favorable characteristics to their offspring.
3. How did the finches of Galápagos Islands adapt to their environment? **Answer** Because the finches were virtually the only land birds present on the islands, they occupied ecological niches commonly filled by other birds. Most of the adaptation was through changes in the animals' beaks. These let the birds develop feeding habits not normal to finches.

17–12
Paleozoic time: the age of invertebrates

Make frequent references to the Calibrated Geologic Time Scale to help students follow the sequence of animal development.

In addition to explanations given in the Text, lack of animal fossils in Precambrian rocks has been attributed to two other causes: (1) The Precambrian sediments are terrestrial, but animals evolved in the oceans rather than on land. This idea is not correct because marine-type limestones are common in Precambrian sediments. (2) Animals evolved in deep waters, from which sediments are not uplifted onto the land. However, the existence of shallow Precambrian seas is indicated by cross-bedding and coarse-grained particles.

Emphasize that the record of life is incomplete. There are many gaps in the fossil record. You might ask students how erosion, metamorphism, and uplift could obliterate or distort the fossil record. Fossils may be melted by magma, dissolved by ground water, reduced to sediments by erosion, or incorporated into mountains by uplift, to name only a few ways.

Life must have been present in Precambrian time. Some rare forms have been recognized in Precambrian rocks.

17–13
Reptiles rule the earth.

It probably will not be necessary to stimulate student interest in dinosaurs. A trip to a museum or a display of dinosaur models in the classroom will be useful. During class discussions ask questions that will help students relate dinosaurs to a particular environment. For instance: How do we know when the dinosaurs lived? How do we know what they ate? How do we know what sort of environment they flourished in? You should point out the error in cartoons, television serials, and toys that portray cavemen as contemporaries of dinosaurs.

17–14
The Cenozoic Era: golden age of mammals

The extinction of the reptilian hordes of the Mesozoic was followed by a marked increase in mammalian development. No one knows whether this was a direct effect or not. Certainly mammals had less competition for food with the decrease in reptilian life. As the students discuss this question, look for logical answers.

In tracing the development of life, point out that climate and plant life were changing also. Thus the appearance of grasses and other flowering plants furthered the expansion of birds and mammals.

17–15
Investigating population growth

Advance preparation

The Teacher's Kit provides sufficient numbers of the small objects from the radioactive decay material. Or, use the beads from the plastic column investigation in Chapter 8.

Time requirements

Pre-lab	10–15 minutes
Lab	15–20 minutes
Post-lab	15 minutes

Materials

The following materials are needed for each group of three or four students:

- Small, uniformly shaped objects (kernels of corn, dried beans, wooden markers, plastic beads), approx. 2000
- Paper cups or small beakers, 10
- Beaker, 250 ml or 400 ml

Pre-lab discussion

When you discuss human population consider such questions as: How long have humans been on the earth? How does the early rate of human population growth compare with the population growth rate today? Why did the rate change?

Tell students that this investigation represents a model of population growth. Students will develop a model of the mathematics of population growth rates.

Notes on procedure

Students may question the need for the 35-second intervals. The reason for this instruction should become evident as students work out answers to the questions. The length of the time interval is arbitrary. Any time interval will do.

You might have one extra setup, in case one entire setup is dumped. At the end of the laboratory time, the entire class can contribute to the pick-up effort.

Preparation of the graph can be assigned as homework.

Range of results

The mathematics involved in answering the questions may tax some students. Assist students when necessary to enable them to accomplish the objectives of the investigation. Guide Figure 17–3 shows the population and the per cent of the beaker's volume without objects. A typical student graph is shown in Guide Figure 17–4.

Post-lab discussion

During the discussion of the graph you may want to consider some of the following: Are there any limitations to the number of people the earth will support? Which factor might limit population growth first? Are there areas in the world where these limits have been reached already? Have we gone beyond the earth's ideal population yet? What problems will we face if we overpopulate the earth? Student answers to these questions will vary, depending on their background and information. The outcome, however, should be an intense discussion on some vital problems facing man today.

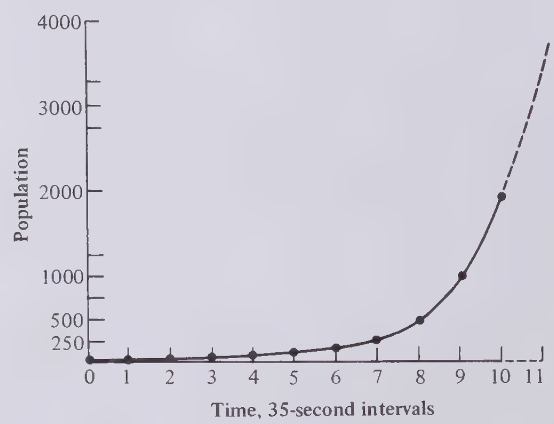
Answers to questions

1. Man's population on the earth is thought to have had a slow start with doubling periods as long as 1 million years. The present world population is thought to be doubling every 37 years. How would the mathematical nature of this growth rate compare to your investigation? **Answer** Both the population in the investigation and on the earth increase in a geometric progression. This means the graphs have the same shape. You can substitute 37 years for every 35-second interval and the numbers will represent actual world population. The slope of the graph would remain the same.
2. The present world population is about 4½ billion people. The earth's radius is about 6400 kilometers and about $\frac{7}{10}$ of its surface is covered with water. What is the present density of human population in terms of number of people per square kilometer? (Area of a sphere $= 4\pi r^2$) **Answer** Approximately 29 people per square kilometer of land surface. A land mass of 154,320,000 square kilometers divided into 4½ billion people = 29 people per square kilometer.
3. Assuming a continuation of the present population growth rate, what will the density per square kilometer be 37 years from now? 111 years? 1110 years? **Answer** In 37 years there would be 70 people for each square kilometer. In 111 years that number of people would have grown to 280. In 1110 years there would be 37,580,000 people per square kilometer.
4. Is space the only limiting factor in determining the maximum human population? If not, describe others. **Answer** A number of limiting factors besides space exist. Probably the most significant is food supply. Communicable diseases, pollution, climate and other geographic limitations, war, and social customs are also factors.

Guide Figure 17–3
Table of population growth for Investigation 17–15.

Time interval	Population	Per cent of empty volume (400 ml beaker)
0	2	99%
1	4	99%
2	8	99%
3	16	98%
4	32	97%
5	64	95%
6	128	93%
7	256	88%
8	512	80%
9	1024	70%
10	2048	50%
11	4096	0%

Guide Figure 17–4
Sample population growth graph for Investigation 17–15.



Suggested additional investigations

Students may wish to consider population growth in your local county or state. Is the growth rate similar to the graph constructed in this investigation? For complete population growth information contact your district office director of the Office of Planning Coordination. Area Chambers of Commerce often have this information as well.

17–16
What lies ahead?

Many times students will be able to suggest ways that man might meet the environmental challenge through legislation, enforcement, and recycling. To stimulate discussion you might also ask questions that encourage students to apply to man the ideas of natural selection. Will man, for example, develop sturdier, more disease-resistant lungs to combat air pollution? Can man develop natural immunities to water pollutants and contaminants? Or will people in the future have to use artificial protective devices such as goggles and gas masks?

What differences do students see between man and animals that became extinct? What similarities? One difference students may suggest is that man does have limited ability to control his environment. Ask students if man may prevent — or at least stave off — his own extinction. There are no real answers to these timely questions, but they are thought-provoking and should provide material for discussion.

Answers to thought and discussion

1. What can fossils tell us about ancient environmental conditions? **Answer** Every organism has characteristics adapted to its environment. Common examples are the body structures used to procure food, move, breathe, and reproduce. By comparing these features to organisms living today, paleontologists are able to determine in what kind of environment an organism thrives.
2. Which animal can adapt to the widest range of environments? Make a list of the evidence to support your answer. **Answer** This is an open question. Many students are likely to suggest man. Man can survive in outer space, in the coldest region of the planet, in the ocean, and under the surface of the land. Others may hold the position that this is not an example of true adaptation. They may suggest bacteria, or other single-celled organisms that can actually live in a wider range of environments than man.
3. Discuss some of the relationships between plant and animal development during the Cenozoic Era. **Answer** Students should point out that plant and animal development occur simultaneously. For example, the expansion of the reptiles must have been accompanied by a tremendous plant growth. Check to see if students recognize that a change in climate affects plants as well as animals. The extinction of the dinosaurs was accompanied by the extinction of many plants.

Discussion of unsolved problems

Paleontologists long have wondered why most animals of the Precambrian apparently lacked hard parts. It has been suggested that the ocean water of that time did not contain the dissolved substances that animals need to construct shells. Another theory is that the seas may have been somewhat more acidic. Most shells are made of chemicals an acidic sea would have dissolved.

Typical Precambrian formations have been subjected to many periods of mountain building and metamorphism. If fossils were present in these rocks, they may have been destroyed or so greatly changed that we don't recognize them. Yet in various parts of the world there are Precambrian rocks that have not been metamorphosed or intruded by igneous bodies. These, too, are virtually without fossils or have yielded the fossil remains of no hard-shelled organisms.

Different scientists have offered many explanations for mass extinction. Some of these are cooling climates, bacterial infections, an increase in the number of predators (including man), atmospheric changes such as loss of the ozone layer which filters out ultraviolet radiation, and excessive sea-level changes that disrupted the environment. Recently it has been suggested that radiation emitted by an exploding star somewhere in space could have destroyed life.

None of these explanations require the sudden death of every plant or animal of a species. It is probable that if something kills many indivi-

duals, the population will decline in numbers to the point of extinction. This happens when the balance between a group of organisms and its environment is destroyed.

The decline in one group may cause another group to become extinct, as well. For example, the decline in numbers of many large grazing animals may have led to the extinction of their predators, the saber-toothed cats. It has also been suggested that the swamp-dwelling herbivorous dinosaurs died when uplift at the end of the Mesozoic drained the swamps where the dinosaurs lived. The carnivorous dinosaurs then died out when their customary prey became extinct. The whole process of extinction probably required many years. (See *Crises in the History of Life* in Supplementary Materials.)

Answers to questions and problems

A

1. What is meant by the term biosphere? **Answer** The world of living things.
2. What are fossils? **Answer** Fossils are the remains or evidence of prehistoric organisms preserved in the rocks of the earth's crust.
3. Why are fossils not likely to be found in metamorphic rocks? **Answer** The heat and pressure of metamorphism usually destroy or alter any fossils present in the rock. Fossils in metamorphic rock are not unknown, however.
4. Why are microfossils especially useful to the paleontologist? **Answer** Because of their small size they are not destroyed in drilling. Microfossils aid the geologist in identifying strata and correlating them in different areas. This is very useful in the search for petroleum and other valuable deposits found in sedimentary rocks below the surface.
5. From what group of animals did birds and mammals probably develop? **Answer** Reptiles.

B

1. A computer responds to outside stimulation. Is the computer alive? **Answer** No, a computer is not alive, but it is an excellent mimic. Most people are not ready to agree that man could build a living thing out of wire and metal.
2. Distinguish between organic and inorganic compounds. **Answer** Organic and inorganic compounds were terms applied originally to compounds present in living and nonliving substances. For example, plants and animals were considered to be organic, and rocks and minerals inorganic. Chemists have expanded the definition of organic compounds to include most carbon compounds, whether they are manmade or natural. The definition of inorganic still refers to the nonliving.
3. Explain the role of decomposers in the calcium cycle. **Answer** Decomposers are organisms that break down decaying organic wastes. This releases calcium and other materials present in these wastes. The material may be returned to the atmosphere, the hydrosphere, or the lithosphere.
4. How do fossils support the theory of organic evolution? **Answer** The development of certain groups, for example, the horses, is well known from the fossil record. These fossils clearly indicate that a small, relatively simple horse in Paleocene time evolved into the larger, more advanced horse of today. In between these two extremes are the remains of fossil horses that show intermediate stages in development.
5. What features developed by the amphibians permitted them to live on land? **Answer** Lungs that permitted respiration on land and limbs for land locomotion.

C

1. Discuss the various ways in which the biosphere, lithosphere, hydrosphere, and atmosphere may interact with one another. Describe the interfaces. **Answer** The question is designed to emphasize the cyclic nature of earth processes. Students' answers should include such ideas as: (1) Chemical elements are continually moving from nonliving objects to living organisms and back again. The biosphere acts as a pump, moving materials around from one place to another. (2) The interfaces between the four different spheres can be in any combination. All four spheres might center around one event. For example, a lily pad can touch rock, water, and air.
2. Outline the process of photosynthesis and explain why it is important to both plants and animals. **Answer** The process of photosynthesis permits green plants to produce new

chemical compounds by the use of light. Water and carbon dioxide are combined to form carbohydrates, water, and oxygen. The process of photosynthesis cannot take place unless chlorophyll and energy are present.

Plants must carry out this process in order to survive. Animals in turn depend directly or indirectly on plants for food. They cannot themselves manufacture the chemical compounds necessary for their existence.

3. Show how the carbon, calcium, and water cycles are necessary for the support and continuation of life. **Answer** Students probably will select an example, plant or animal, and show how cycles help it to survive. For any living organism these materials must continually be cycled between the organic and inorganic worlds.
4. Explain how the differences of the Galápagos finches supported Darwin's theory of natural selection. **Answer** Through changes in their beaks over many generations, the finches became adapted to a wide variety of habitats which are normally filled by other birds.
5. Describe the adaptions made by the amphibians as they evolved into reptiles. **Answer** The reptiles produced an egg that could be hatched on land. This egg eliminated the water larval state necessary to the amphibians. Reptiles also have glands that prevent their skin from drying out in the air. They also developed new skeletal features for locomotion. Thus the reptiles have no need to live in the water, even to reproduce.
6. What are some of the environmental problems faced by modern man? How might they be remedied? **Answer** Pollution of air and water, destruction of land and other natural resources, and population growth are only some of the general problems. Read the students' remedies carefully — the adults' remedies aren't working too well.

Supplementary Materials

Reference books

Beerbower, James R. *Field Guide to Fossils.* ESCP Pamphlet PS-4, Houghton Mifflin Company, Boston, 1971. (Paperback)

Beerbower, James R. *Search for the Past: An Introduction to Paleontology,* 2nd ed. Prentice-Hall, Inc., Englewood Cliffs, N.J., 1968.

Boyer, Robert E., and Higgins, Jon L. *Activities and Demonstrations for Earth Science.* Parker Publishing Co., West Nyack, N.Y. 1970.

Clark, David L. *Fossils, Paleontology, and Evolution.* William C. Brown Co., Dubuque, Iowa, 1968. (Paperback)

Dunbar, Carl O., and Waage, Karl M. *Historical Geology,* 3rd ed. John Wiley & Sons, Inc., New York, 1969.

Easton, William A. *Invertebrate Paleontology.* Harper & Row, Inc., New York, 1960.

Heller, Robert L., *et al. Geology and Earth Sciences Sourcebook.* Holt, Rinehart & Winston, Inc., New York, 1971. (Paperback)

Matthews, William H., III. *Fossils: An Introduction to Prehistoric Life.* Barnes & Noble, Inc., New York, 1962. (Paperback)

McAlester, A. Lee. *The History of Life.* Prentice-Hall, Inc., Englewood Cliffs, N.J., 1968. (Paperback)

Moore, Ruth and the Editors of *Life. Evolution.* Time-Life, Inc., New York, 1962.

Simpson, George G. *Horses.* Doubleday and Company, New York, 1961.

Simpson, George G. *Life of the Past: An Introduction to Paleontology.* Yale University Press, New Haven, Connecticut, 1953. (Paperback)

Stirton, R. A. *Time, Life, and Man: The Fossil Record.* John Wiley & Sons, Inc., New York, 1959. (Paperback)

Stokes, William L. *Essentials of Earth History: An Introduction to Historical Geology,* 3rd ed. Prentice-Hall, Inc., Englewood Cliffs, N.J., 1973.

Periodicals

Brues, Charles T. "Insects in Amber." *Scientific American,* November 1951. (Also Scientific American Offprint #838.)

Kettlewell, H. B. D. "Darwin's Missing Evidence." *Scientific American,* March 1959. (Also Scientific American Offprint #842.)

Lack, David. "Darwin's Finches." *Scientific American,* April 1953. (Also Scientific American Offprint #22.)

Matthews, William H., III. "Science Unit on Fossils." *The Science Teacher,* November 1962.

Newell, Norman D. "Crises in the History of

Life." *Scientific American,* February 1963. (Also Scientific American Offprint #22.)

Wulfson, Stephen. "Rubber Molds." *Science and Children,* March 1967.

Yochelson, Ellis L. "Raising the Dead." *Science and Children,* March 1967.

Films

The Earth is Born, Prehistoric Animals, Age of Mammals, Reptiles, The Galápagos Islands, Evolution Today, and *Darwin.* Color. Life Filmstrips.

Earth Science Series. Color. Film Associates of California. Includes: "Life Through the Ages," "Animals of the Tar Pits," "Dinosaurs," and "Paleontologists at work."

The Fossil Story. 18 minutes, color. Shell Oil Company.

Fossils. Color. Encyclopaedia Britannica Educational Corp. Set of filmstrips with Teachers Guide. Includes: "How Fossils are Formed," "Collecting and Interpreting Fossils," "Fossils and the Relative Ages of Rocks," "Fossils and Prehistoric Environments," and "Fossils and Organic Change."

Fossils Are Interesting. 9 minutes, color. Film Associates of California.

Fossils: Clues to Prehistoric Times. 10 minutes, color. Coronet Films.

An Introduction to Fossils. Color. Ward's Natural Science Establishment. Set of six filmstrips with teacher's manual. Nature and uses of fossils and various types of prehistoric plants and animals.

Life Long Ago. Color. Society for Visual Education Filmstrips. Set of six captioned filmstrips with Teacher's Guide. Includes: "Up Through the Coal Age," "When Reptiles Ruled the Earth," "Mammals Inherit the World," "How We Know About Life Long Ago," "Hunting Fossils," and "Stories That Fossils Tell."

Prehistoric Animals of the Tar Pits. 12 minutes, color. Film Associates, 1957.

Other aids

Earth History Model. Hubbard Scientific Company. A plastic model of a composite geologic column complete with plastic fossil reproductions.

Fossil Laboratory. Hubbard Scientific Company. A set of four charts, student laboratory manual and lesson plan, and 20 plastic fossil reproductions.

Fossils Through Time. Science Kit, Inc. A complete fossil laboratory of plastic fossils for various portions of geologic time. Special unit on evolution of the horse. Instruction book included.

Paleogeographic Map, Rock, Fossil Set. Hubbard Scientific Company. Six Paleogeographic maps and 36 specimens of rocks and fossils for laboratory study.

18. Development of a Continent

Chapter Objectives

After completing this chapter, students should be able to:

1. Use the principles of uniformitarianism, superposition, and fossil correlation to interpret rocks.
2. Use cross sections, geologic maps, and other geologic illustrations to reach conclusions about the geology and history of an area.
3. Describe the general structure and historical development of the main geologic regions of North America.
4. Discuss a major unsolved problem in the geologic record such as how continents form or how geosynclines develop.
5. Describe typical features of a landscape shaped by glaciers.

Teaching the Chapter

This chapter summarizes the geologic processes and rates of change students have studied since Chapter 11. It concentrates on the geologic evolution of North America. The material is presented sequentially, beginning with the Precambrian foundations of the continent and ending with the effects of Pleistocene glaciation.

Investigations in this chapter provide students with situations similar to those faced by field geologists. Students attempt to decipher the sequence of certain geologic processes from the record in the rocks. They also trace the paths of ancient glaciers from geological data.

Suggested time required

It should take five to seven periods to discuss the topics and complete the investigations in this chapter.

18–1
Investigating Precambrian rocks

Advance preparation

Prepare a transparency of Figure 18–1.

Time requirements

Pre-lab	5 minutes
Lab	15 minutes
Post-lab	15 minutes

Pre-lab discussion

Assign students to work out the rock sequence a day or two before you plan to complete the investigation in class. The rock symbols are the same in each cross section.

Notes on procedure

Guide Figure 18–1 keys each of the rocks. The age of each rock is as follows:

8 1200 million years
7 1500 " "
6 1800 " "
5 2150 " "
3 and 4 — older than 2150 and younger than 2500 million years
2 2500 to 2700 million years
1 older than 2500 to 2700 million years

After you give students the dates, they can complete the sequence in each cross section and correlate all three cross sections.

Range of results

By applying the principle of superposition and observing intrusions and other evidence, students can arrange many of the rocks in proper sequence. There are a few instances where it is impossible to do this without dates. The correct sequence is listed in the answer to question 1.

Post-lab discussion

Students should reach a consensus about the sequence of events. Allow students who disagree about an arrangement to explain their reasons. The class can vote, or decide in some other fashion which order to accept.

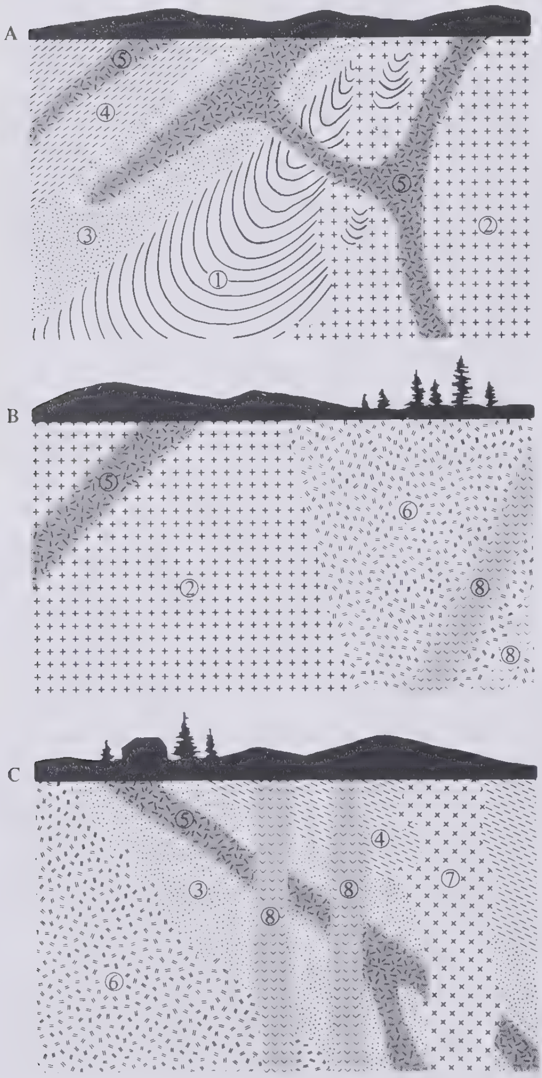
Answers to questions

1. Can you now put all of the rock units in a relative time sequence? **Answer** See Guide Figure 18–1. In A, the relative ages from oldest to youngest run 1, 2, 3, 4, 5. The folded sedimentary sequence 1 has been intruded by the igneous body 2. Fragments of 1 floated into 2 before crystallization. Following a period of erosion, sedimentary sequence 3 was deposited across 1 and 2. Sedimentary sequence 4 was in turn deposited upon 3. Rock 5 cuts across 1, 2, and 3. It is presumed younger than 4 as well because of similarity of rock types. This evaluation would have to be tested by finding an exposure where the two disconnected portions of 5 join.

   In B, intrusive 2 is cut by and is therefore older than intrusive 5, and by the-same reasoning intrusive 6 is older than intrusive 8. However we do not know which side of the diagram is older. The boundary between 2 and 6 may be an intrusive one, or it may be a fault. Therefore, 2 could be older than 6, and 5 younger than 8. More information is needed.

   In C sedimentary sequences 3 and 4 are cut by intrusive 5, and all three are cut by intrusive 7. Intrusive 6 cuts and is therefore younger than sequence 3, but the relation of 6 to 4, 5, and 7 is not known. Intrusive 8 is younger than intrusive 6, but its relation to intrusive 7 is not known from C.
2. Do the ages of these rocks agree with the order you worked out from the cross sections? **Answer** The sequence students worked out based on geologic relationships should agree with the dates. The radiometric dates may help place some of the undetermined units.

Guide Figure 18–1
Key to the sequence of rock layers in Investigation 18–1.



18–2
The Precambrian record
18–3
Four billion years of history

Students may wonder how scientists recognize the site of a former geosyncline. In earlier chapters the Text described the thick deposits of sediment, in some cases interbedded with lava flows, characteristic of geosynclines. The rocks of geosynclines are ultimately folded, intruded, and uplifted into mountain ranges. Long periods of erosion, during which the elevated rocks are completely removed, leave only the roots of the mountains. Scientists conclude that the thick, folded sedimentary-volcanic sequences in the Canadian shield represent former mountain ranges that were built from early geosynclines.

Earlier chapters discussed reasons why fossils are so rare in Precambrian rocks. In recent years, new chemical techniques and new instruments,

especially the electron microscope, have made it possible to examine Precambrian rocks in much more detail than was possible before. Scientists have been able to show that some Precambrian rocks were formed through the activity of living organisms. They contain either fossils or hydrocarbons found in younger rocks only in association with fossil organisms.

In general, the algal-type fossils are very similar to modern families of algae. Many of the forms required oxygen to function. These are remains of photosynthetic organisms that were living in shallow, current-disturbed, possibly marine water over three billion years ago. The very early atmosphere of the earth probably was without oxygen, so these fossils may have lived at a time when oxygen may have existed only locally. Perhaps it was concentrated in isolated localities where photosynthetic plants were producing it. Oxygen may have become more abundant as the photosynthetic plants became more abundant and widespread.

Answers to thought and discussion

1. What evidence is there that the Canadian Shield has been stable since the early Paleozoic? **Answer** (1) Erosion of the Canadian Shield has removed all but the roots of the oldest mountains. Such extensive erosion must have required a long exposure of the region to agents of erosion. (2) Sediments representing the Paleozoic are so thin and cover such small areas that it seems unlikely that they were ever very thick or extensive. (3) Absence of rocks representing most of the periods of the Paleozoic and later periods suggest that during most of these eras the Shield was above sea level. During this time it was being eroded rather than being covered with deposits.
2. What evidence is there that the Canadian Shield has not always been stable? **Answer** (1) The presence of folded geosynclinal rocks intruded by igneous rocks then metamorphosed indicates mountains and mountain-building processes. (2) Mountain building occurred at different times and at many places in the Shield. (3) The continent may have grown from a continent that was originally much smaller. This could only happen if conditions were very unstable in the Shield during much of Precambrian time.
3. What evidence is there that North America developed from a smaller continent? **Answer** Radioactive dates obtained from Precambrian rocks in North America show that some of the oldest rocks are in the center of the Shield. Successively younger Precambrian rocks are found outward from this region.

18–4
The Paleozoic record

Students may wonder why the presence of large amounts of limestone, salt, and coal in Paleozoic formations is so important. You can remind students that limestone deposits are formed either by precipitation of carbonates from sea water or by the accumulation of countless skeletons of dead organisms.

Lack of salt deposits in the Precambrian record suggests two possibilities. Precambrian seas might have been much less saline than present seawater, or even than seawater since the beginning of the Paleozoic. It is also possible that conditions necessary for formation of salt deposits, evaporation of sea water in shallow basins, for instance, did not exist in Precambrian seas.

Coal deposits are formed from the accumulation of organic matter, primarily vegetation. Evidence for the existence of land plants before the beginning of the Devonian period is very scarce. This scarcity of plant life would explain the lack of coal beds in Precambrian formations.

One way you can emphasize the migration of seas during the Paleozoic is to reproduce paleogeographic maps illustrating the extent of land areas during the beginning of each period within the Paleozoic Era. If you make the maps on tracing paper or clear plastic you can compare them by overlaying each period on the one before.

18–5
The Mesozoic-Cenozoic record

Action Instead of tracing paper, students also may use sheets of clear plastic. If they use crayons or marking pens of different colors the boundaries should be easy to see.

While the sedimentary rock record is not complete for all of the Eras, students should observe a definite pattern. Radiating away from the oldest Shield rocks of north-central and eastern Canada, the rocks become increasingly younger. Thus, a path from northern Ontario toward Southern California passes over surface exposures first of Precambrian, then of Paleozoic, Mesozoic, and Cenozoic rocks. This is a general trend, but there are many exceptions.

You might ask students, for example: Would you expect to find Mesozoic fossils in Ohio, Pennsylvania, and New York? They would be uncommon. Where would Paleozoic fossils be rare? Some of the places are Montana, Colorado, and Texas. In this way you can use the maps to discuss the distribution of life forms from the Paleozoic to the Recent covered in Chapter 17. If you have examples or slides of appropriate fossils you can use them to enhance the discussion.

Answers to thought and discussion

1. How do geologists know that the early Cambrian seas were shallow? **Answer** Geologists have found fossils of animals like brachiopods and trilobites that lived only in shallow water. They also have found shallow water indicators such as salt deposits, sandstones, and shales.
2. In what era of geologic time are we now living? **Answer** The Cenozoic Era.
3. What evidence shows that thicker rock layers in the geosynclines were formed during the same time interval as the thin layers found in the interior of the continent? **Answer** Correlation of geosynclinal rock with those of the continental interior is accomplished almost exclusively by means of fossils. James Hall used fossils to discover that great thicknesses of rocks in the Appalachian area were the same age and represented the same length of time as a much thinner sequence of rocks in the interior of the continents. Earth scientists today use fossils to correlate rocks when they work out the details of the position and nature of old geosynclines and the lengths of time they existed.
4. What destroyed the geosynclines that existed along the east and west coasts of North America during the Paleozoic and Mesozoic eras? **Answer** Rocks in the geosynclines were folded, faulted, intruded by igneous rocks, and uplifted into mountains. In both instances, the mountains developed over a long period of time. The development began near the early or middle part of the era and extended into the next era.
5. In the future, what might happen to the Gulf coastal region where the present land surface is nearly flat, close to sea level, and underlain by greater thicknesses of sedimentary rocks? **Answer** If the Gulf Coast is the site of a geosyncline and its history parallels that of earlier geosynclines, mountains may form. Sedimentary rocks in the region may be folded, faulted, intruded by igneous rocks, and uplifted to elevations as high as those seen at present in the Alps and Himalayas.
6. When did North America reach its present size and shape? **Answer** If one were concerned with details of the coasts the most accurate answer would be "today." The continent reached its general size and shape during the very late Pleistocene.

18–6
Theory and evidence
18–7
Features left by glaciers

Students may wonder how glaciers could produce sorted outwash at one place and unsorted till at another. When glaciers advance over soil and bedrock, the ice picks up the material as an unsorted mixture of soil, pebbles, and boulders. The unsorted debris is carried along frozen in the ice. As the glacier moves across rough ground, some of the unsorted till is "plastered" against bedrock projections and hills. Where the glacier is melting, the debris is gradually let down to rest on bedrock. In either case, the debris remains unsorted and unstratified.

In some places meltwater streams flowing on and through the ice (in crevasses and tunnels) pick up some of the debris in the ice. The streams sort the material and deposit it in stratified layers. Those deposits may be on or under the ice, or they may be downstream well away from the ice.

There is another way that glaciers produce irregular landscapes. Blocks of ice may be buried under till or outwash. As the blocks melt, the land surface above is let down into the cavity formed. This process produces surfaces of glacial deposits that are irregular and bumpy.

Demonstration Students can illustrate at home how the melting of buried ice blocks can produce an irregular surface on glacial deposits. Fill a pan with sand or dirt to a depth of about 10 centimeters, then bury several ice cubes in the sand. Smooth the surface, and let the pan stand overnight. Students should have no difficulty relating the rough surface produced on the sand to the rough surfaces found on some glacial deposits. You could do this in class and have students observe the results the next day.

In some instances, old beaches and other coastal features are still above sea level because water is still stored in glaciers in Greenland, Antarctica, and some mountain ranges. These features were formed during the high water stages between ice ages. In other instances, the beaches may be above sea level because the coastal region has been uplifted. This is common along the western coast of North America and in New England north of Boston.

18–8
Investigating an ice age puzzle

Advance preparation

Have graph paper on hand to distribute to the students.

Time requirements

Pre-lab	5 minutes
Lab	30–40 minutes
Post-lab	15–20 minutes

Pre-lab discussion

Many students will need some explanation of the data in Appendix E. Some teachers find it useful to discuss with the class the information for locality #1.

Notes on procedure

It simplifies discussion later if all students use the same key of colors and symbols on their graphs. Guide Figure 18–2 shows a key you can use or modify.

Range of results

Student cross sections should look like Guide Figure 18–2. If students use different scales the graphs will have vertical and horizontal exaggeration. This does not make them incorrect.

Post-lab discussion

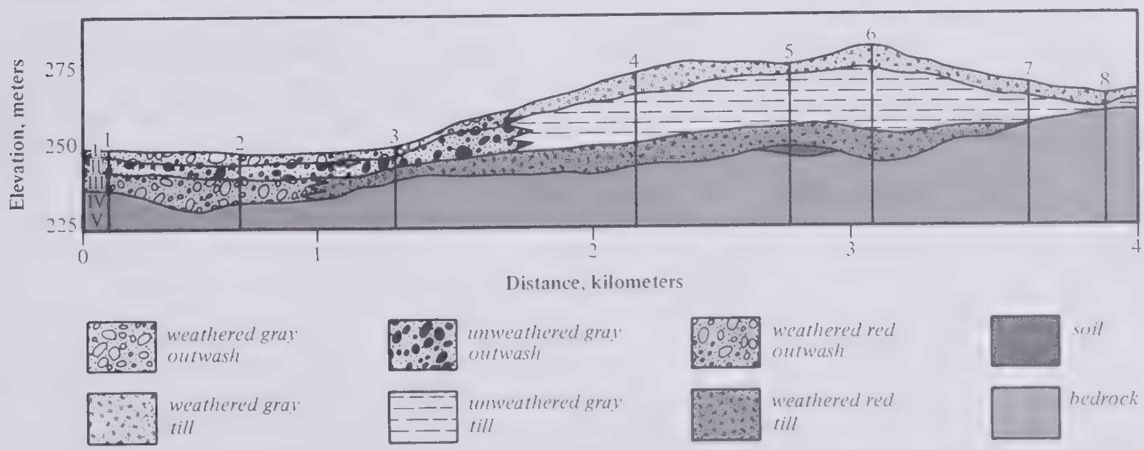
Because the vertical scale is much larger than the horizontal, the surface looks steep. You could ask a student to plot the surface in true scale on the chalkboard. It is actually a very gentle slope.

Some of the questions you can ask students are: How many glaciers were there? How far did each one travel? What evidence did they leave behind? Why is there so little soil on top of the bedrock at Station 5?

Answers to questions

1. Which of the till layers is apparently the older one? **Answer** The red layer (III).

Guide Figure 18–2
Sample cross section for Investigation 18–8.



2. What evidence shows that a long time elapsed between deposition of the two layers? **Answer** The red till and outwash (III) are weathered to a depth of several meters.
3. What could cause this lapse of time between periods of deposition? **Answer** There was a period of several thousand years between the recession of the first glacier and the advance of the second.
4. Which till are the south-trending grooves connected with? **Answer** Red (III).
5. Explain why there are no south-trending grooves at localities 7 and 8. **Answer** The second glacier erased them and left southwest-trending grooves.
6. Describe the sequence of glacial activity in this area. **Answer** A glacier traveling southward brought in red material (III) which it deposited as it receded. Later, a glacier traveling southwestward brought in gray material (I and II). In both cases the southern boundary of the glaciers occurred in this area.

Answers to thought and discussion

1. What evidence is there that the drift covering the northern United States and southern Canada was deposited by glaciers? **Answer** The presence of till, outwash, polished and scratched surfaces, isolated boulders, surface features in till and outwash such as piled-up ridges and holes left from melting blocks of ice, and in mountainous regions the shapes of valleys.

   Although several of the features might be produced by agents other than ice, the combination of all is found only in association with glaciers. Some students may note that it is through comparison with the deposits of existing glaciers that we conclude that older till and outwash were deposited by glaciers. The conclusion is based on the principle of uniformitarianism.
2. Why do scientists think that outwash is deposited by water rather than by ice? **Answer** Outwash is composed of stratified and sorted sediment. Observation of existing glaciers demonstrates that ice deposits unsorted, unstratified material (till). Meltwater from the ice deposits sorted, stratified silt, sand, and gravel.
3. What evidence indicates that there was more than one glacial advance during the Pleistocene Epoch? **Answer** In many places within the glaciated regions of North America and Europe two or more sheets of drift are found, one above the other. The layers are of distinctly different ages. The ages can be determined by the presence of various kinds of material between the layers. There are (1) weathered zones, including soils which take thousands of years to form; (2) peat and lake deposits; (3) fossil trees; (4) wind-deposited silt, pollen, and spores; and (5) fossils of mammoths and other Pleistocene animals.
4. How can earth scientists locate the centers from which the ice sheets advanced? **Answer** The orientation of some glacial deposits and of several erosional features are useful clues to the direction from which the ice flowed. You can plot the directions back to the area where the ice accumulated. At some places, scratches and grooves were cut in two directions and show that the direction of ice flow must have changed. Ridges of till built at the edges of the glaciers record the positions of the margins. Some boulders found in glacial deposits are of very distinctive rock types. Some bedrock hills are shaped by ice erosion so that their long axes are parallel to ice flow or their smooth slopes are found on the side of the hill nearest to the glacier.
5. Are we living during an ice age, in a period between glacial advances, or at the end of an ice age? What is your evidence? **Answer** Until we learn more about why glaciation occurs, we cannot decide whether we are living in a glacial, an interglacial, or a postglacial age. Although 90 per cent of the earth is glacier-free, 10 per cent is not. If glaciers still exist, can we say that the ice age has ended? If glaciers disappear completely, we shall be able to conclude that we are living either in an interglacial period or at the end of the Ice Age. Should the glaciers ultimately advance to reoccupy much of northern North America and Europe, the answer will be obvious to our descendants.

Discussion of unsolved problems

In whatever manner the continents originated, it is not surprising to find evidence in the oldest rocks supporting the existence of geosynclines and the development of mountains. These old rocks reinforce the view that such geologic processes as erosion, sedimentation, volcanism, and metamorphism were operating during the development of the continent just as they are now. We can see that these processes influenced the earth, but the evidence doesn't answer the basic questions. Why is the crust unstable? Why does the crust become unstable in certain regions so that geosynclines develop? Scientists need to learn much more about the earth before these and many other questions can be answered.

Students may be puzzled by the hypothesis that correlates glacial periods with the *absence* of ice in the Arctic Ocean. Cooling alone is not sufficient to produce glaciation. For glaciers to grow, there must be not only low temperatures but also adequate precipitation. This water evaporates into the air from the open ocean. Without sufficient expanse of open water to evaporate and then precipitate, glaciers could not exist.

Answers to questions and problems

A

1. What types of rocks are generally associated with plains and plateaus? with mountain ranges? **Answer** Nearly horizontal or gently tilted sedimentary rocks, most of which are Paleozoic or younger, generally are found at the surface in plains and plateau areas. Strongly folded and faulted sedimentary, metamorphic, and igneous rocks generally are associated with mountain ranges.
2. Why is the trilobite *Olenellus* so useful for rock correlation? **Answer** *Olenellus* is found only in the oldest Cambrian rocks, and it or its close relatives are found on every continent.
3. What principles are used to arrange layers of rocks in sequence? **Answer** The principles of superposition, cross-cutting relations, and uniformitarianism.
4. In what ways do deposits of till and outwash differ? **Answer** Material deposited directly by the ice (till) is unsorted, lacks internal stratification, and is distributed over hills and valleys alike. Material deposited by meltwater from the ice (outwash) resembles other water-deposited sediments except that it is closely associated with till and can be traced upstream to the till.
5. What features of glaciation are used to indicate the direction in which the ice moved? **Answer** Scratches and grooves are cut in the direction the ice is moving. Sometimes glacial deposits and rock hills are eroded by flowing ice. Some pebbles and boulders can be traced back to the area from which they came.
6. The Great Lakes and Hudson Bay occupy large depressions. How were these depressions formed? **Answer** The present Great Lakes basins occupy what were lowlands prior to the advent of the earliest Pleistocene glacier. These lowlands served to channel the ice as the glaciers advanced. The ice eroded the lowlands to depths considerably below sea level. At the time of maximum glacial spread, the great mass of ice was sufficient to depress the crust beneath it. Hudson Bay also occupies a depression that may have been a lowland prior to glaciation. It owes much of its depression to the weight of Pleistocene ice.

B

1. Describe the arrangement of mountains and lowlands in North America. Why are they arranged in this way? **Answer** Mountains are found along the borders of the continent. They occupy the positions of former geosynclines, apparently because geosynclines eventually develop into mountains.

   By contrast, the interior of the continent seems to have been stable since the Precambrian. All of the rocks are nearly horizontal. They have not been deformed or uplifted into mountains, providing evidence that the interior of the continent was much more stable than its borders during this interval.
2. Igneous and metamorphic rocks commonly are exposed in mountain ranges. How do you explain their presence at the surface of the Canadian Shield? **Answer** Rocks now exposed

in the Canadian Shield were originally deeply buried parts of ancient mountain ranges.

3. Why is the rock record of the geologic history of a continent less complete for earlier than for later eras? **Answer** The rock record is incomplete partly due to erosion. The record may be difficult to read because of metamorphic changes after the rock was formed.
4. What might the earliest living things have been like? Why have no fossil traces of them been found? **Answer** The oldest fossils found so far are bacteria. Scientists believe that viruses may have existed on the earth long before bacteria. Viruses probably are similar to the earliest living things. Most of the processes of fossilization would destroy something as microscopic and fragile as a virus. Even if a virus were fossilized, it would be hard to tell it from a complex molecule that never was a living object.
5. Why are some fossils useful for correlating sedimentary rocks but not for explaining the environments in which the rocks formed? Why are other kinds of fossils useful for explaining the environments in which the rocks formed, but not for correlation? **Answer** Some organisms can tolerate wide ranges of salinity, light, current and wave action, bottom conditions, and temperature. These organisms become geographically widely distributed. Other organisms live only in environments in which the factors vary within narrow limits. Some fossil species lived only for a short time in geologic history. Others have remained essentially unchanged for millions of years.

   The most useful fossils for correlation purposes are those which existed only during a short time span but had wide environmental tolerance. We can determine the present limits of environmental tolerance for the closest descendants of the fossil species. This establishes ancient environmental conditions with some certainty.
6. There have been several explanations for the migration of animals and plants from continent to continent. List some of them and explain what kinds of evidence are needed to support each. **Answer** Land bridges like the Isthmus of Panama might have connected continents. Evidence would be needed that the sea level had changed enough to create the bridge. Animals might have swum and plants floated from one continent to the next. Even with favorable winds and currents, animals could not swim far. Resistant seeds like coconuts could travel long distances. Animals and plants might have rafted on vegetation from one continent to the next. It would be hard to find evidence for this. Larvae, spores, and pollens might have been trapped in bird feathers. You could see if modern birds carry passengers. If the continents once were part of a single continent, animals and plants could have migrated without barriers. The other evidence for moving continents indicates that the split was long before most animals and plants existed. This explanation accounts only for migrations that occurred before the continents broke apart.
7. What evidence indicates the presence of extensive glaciation in the Northern Hemisphere during the Pleistocene Epoch? **Answer** Among the evidence which originates through erosion are the grooves and scratches cut by glaciers into bedrock, glacier-carved bedrock hills, and U-shaped valleys. Evidence which originates through deposition are the till and outwash deposits, including the ridges of till that formed at the ice margins. Glaciers also deposited boulders of rock unlike the rock where they are found.
8. Parts of North America are still reacting to the presence of the tremendous weight of the Pleistocene ice. What are these reactions and where are they noticeable? **Answer** Parts of the North American continent that were depressed under the great weight of Pleistocene ice have been rising gradually. The uplift is especially noticeable in the regions of Hudson Bay and the Great Lakes.

C

1. If the oldest known rocks are sedimentary, does this mean that the first rock-forming process that affected the earth was sedimentation? **Answer** No. The sediments must have come from an older rock. There always must be a source undergoing erosion to form sediments.
2. What does the presence of fossil coral reefs

in arctic regions probably indicate about the ancient climate of those regions? What other possible explanation could there be? **Answer** The climates of those regions probably were much warmer than they are at present. An alternate explanation might be that corals could tolerate much colder temperatures in those ancient times.

3. How will studies of the ocean floor help to explain the origin of continents? **Answer.** Characteristics of the crust, locations of mobile belts, and several other factors bear on both the continents and the ocean basins. In order to construct a theory of continental origin, the origin of ocean basins must be considered. The theory must account for mountains in ocean basins as well as on continents. Because the two types of structures are so closely related, studies of the ocean basins and continents must be carried on simultaneously.
4. There are indications that climates in the Northern Hemisphere are gradually becoming warmer. What effect could this have on the remaining glaciers and sea level? How might this be related to the Pleistocene ice age? **Answer** If climates continue to become warmer, existing glaciers might melt. If they were to melt, the water returned to the sea would cause sea level to rise. The rise would submerge coastal lowlands, including most of the important cities around the world. It may well be that there were no glaciers in polar regions during some or all of the interglacial stages of the Pleistocene Epoch.

Supplementary Materials

Reference books

Clark, Thomas H. and Stearn, Colin W. *Geological Evolution of North America*, 2nd ed. The Ronald Press Company, New York, 1960. This edition has an especially good map section.

Dunbar, Carl O. *Historical Geology*, 2nd ed. John Wiley & Sons, Inc., New York, 1960. Especially good treatment of the way in which inferences are drawn from rock characteristics and fossils.

Dyson, James L. *The World of Ice*. Alfred A. Knopf, Inc., New York, 1962. Very readable account of ice in world today and throughout Pleistocene Ice Ages. Excellent illustrations.

Holmes, Arthur. *Principles of Physical Geology*. The Ronald Press Company, New York, 1965.

Kay, Marshall and Colbert, Edwin H. *Stratigraphy and Life History*. John Wiley & Sons, Inc., New York, 1965. Somewhat advanced in its treatment.

Kummel, Bernhard. *History of the Earth: An Introduction to Historical Geology*. W. H. Freeman & Co., San Francisco, 1961. Correlation of data from several continents.

Rutten, M. G. *Geological Aspects of the Origin of Life on Earth*. American Elsevier Publishing Co., Inc., New York, 1962.

Simpson, George Gaylord. *The Meaning of Evolution*. Yale University Press, New Haven, Conn., 1949. Still one of the best general summaries available.

Stokes, William L. *Essentials of Earth History: An Introduction to Historical Geology*, 2nd ed. Prentice-Hall, Inc., Englewood Cliffs, N.J., 1966.

Woodford, Alfred O. *Historical Geology*. W. H. Freeman & Co., San Francisco, 1965. Especially good discussion of problems of correlation and of radioactive dating.

Periodicals

Dietz, R. S. "Geosynclines, Mountains, and Continent Building." *Scientific American*, March 1972.

Engel, A. E. J. "Geologic Evolution of North America." *Science*, April 12, 1963.

Ewing, Maurice and William L. Donn. "Theory of Ice Ages, Part I." *Science*, June 15, 1956; "Part II." *Science*, May 16, 1958.

Stokes, William L. "Another Look at the Ice Age." *Science*, October 28, 1955. Proposes that conditions in the Arctic Ocean control glacial-interglacial episodes.

Tilton, G. R. and S. R. Hart. "Geochronology." *Science*, April 26, 1963.

Films

Evidence for the Ice Age. 18 minutes, color. American Geological Institute—Encyclopaedia Britannica Educational Corporation, 1966.

Excellent film showing features of continental glaciation.

Glacier Park Studies. 22 minutes, color. Bailey Films, 1958. A general geologic and botanical summary.

In the Beginning. 28 minutes, color. John J. Hennessy Productions, 1957. Reviews the geologic history of the Grand Canyon region in detail.

The Riches of the Earth. 18 minutes, color. National Film Board of Canada. Clear expression of continual geologic change.

Rise and Fall of the Great Lakes. 18 minutes, color. National Film Board of Canada, 1970. Highly recommended, award-winning film presenting a novel view of the past, present, and future of the Great Lakes area.

Story in the Rocks. 17 minutes, color. Shell Oil Company, 1962. Brief introduction to origin and occurrence of fossils and their use in oil-well correlation, followed by presentation of vertebrate reconstructions and summary of geologic history from Carboniferous to Ice Age.

The World We Live In. Life Filmstrips, 1953. The series includes: *Earth is Born, Face of the Land, Golden Age of Mammals, Reptiles Inherit the Earth.*

The following filmstrips are produced by the American Geological Institute—Encyclopaedia Britannica Educational Corporation: *Fossils and Prehistoric Environments, Fossils and Organic Change, How a Glacier Shapes Its Valley, Measuring Movements of the Earth's Crust, Reconstructing the Ice Age, Some Side Effects of the Ice Age.*

Other aids

Evolution of North America. General Aniline and Film Corp., New York. Overhead transparencies.

Glacial Map. Geological Society of America, 231 East 46th Street, New York, New York 10017. Shows glacial deposits of North America. Scale: 1 inch = about 73 miles. Price $2.00.

Petroleum packet: free maps and pamphlets for teachers. American Petroleum Institute, Education Department, 1271 Avenue of the Americas, New York, New York 10020.

United States Geological Highway Map Series. American Association of Petroleum Geologists, P.O. Box 979, Tulsa, Oklahoma 74101. $1.00 each folded; $1.25 rolled. Geological Highway Maps covering the United States, exclusive of Alaska and Hawaii. One side contains geologic map of area, including highways and other features. Around border of geologic map are geologic sections indicating geologic time and various rock types. Reverse side of sheet contains several cross sections of the area, a tectonic map showing faults, uplifts, and similar features, a physiographic map, and geologic history of region by use of small maps showing locations and patterns of subsidence, uplift, mountain building, deposition, erosion, and igneous activity. Series of 11 maps.

unit five

Exploring the Universe

19. Exploring the Moon

Chapter Objectives

After completing this chapter, students should be able to:

1. Identify which principles and processes used in studying the earth apply to the study of the moon.
2. Analyze the topography of the moon's surface.
3. Establish the order in which dominant features formed on the moon.
4. Give examples of how study of the moon will provide greater understanding of the development of the earth and the solar system.

Teaching the Chapter

This chapter discusses how the same processes that occur on the earth have affected the moon.

Students begin by identifying similarities and differences between earth and lunar environments. They make hypotheses about how the differing environments affect the geologic processes at work on the earth and moon. At the end of the chapter students are challenged to plan the survival activities of a space crew wrecked on the moon. Students use their knowledge of the lunar environment to decide what supplies the space crew should salvage.

In this chapter you will find many references to material covered in earlier chapters. How much you review this material will depend on how extensively you covered similar material with your class in previous chapters.

Suggested time required

It should take three to five days to discuss the topics and complete the investigations in this chapter.

Section Notes

19–1
The view from earth

How do astronomers know that there are no oceans on the moon? The most obvious answer is that they do not see them. Increasing magnification of any part of the moon reveals more and more solid features such as craters. Also, there is no sun glint. The sun's reflection off water is prominent in photographs of the earth from space.

The sequence of craters described in the Text presents a series of increasingly older features. While it may be millions of years old, Copernicus is one of the moon's youngest craters. Presumably Copernicus represents the initial form of all the craters. It also may be the earliest stage of a mare basin, since scientists believe mares are craters filled with lava. The rays blend into the ejecta blanket surrounding the crater Copernicus. Because of this, the rays are considered to be chiefly streaks of powdered rock ejected or thrown out of the crater. However, they also are partly the result of newer cratering that has cast out light-colored material onto portions of the moon's surface.

Craters that do not have rays, such as Eratosthenes and others described here, are clearly older. Their topography is much more eroded. This suggests that the rays fade with time, but the cause of this fading is not precisely known. They may be buried by the ejecta from small meteoritic impacts. Chemical changes might also darken the rays in time. This could happen if oxygen atoms are removed from the lunar material by bombardment from solar protons and alpha particles (helium nuclei).

The mare ridges should remind students of

folded mountains. If the class discussed geologic structures in detail, students may suggest that the ridges resemble anticlines. You could remind students that on earth anticlines, domes, and folded mountains are eroded as they form. Consequently earth scientists do not know just how such structures would look if there were no erosion. The mare ridges may represent anticlines that have developed without the effects of significant erosion.

19–2
Investigating landscapes on the moon

Time requirements

Pre-lab	5 minutes
Lab	20 minutes
Post-lab	15 minutes

Materials

The following materials will be needed for each group of two students:

- Transparent plastic sheet
- Marking crayons
- Moon photograph from stereo atlas in Stereo Photo Kit
- Map of Monte Apenninus region of the moon from Teacher's Kit

Pre-lab discussion

Remind students to mark on the plastic sheet, so that changes can be made easily. If possible, use a full-page reproduction from the stereo atlas instead of Figure 19–11.

Some students may need a review of superposition at this time.

Notes on procedure

Once students begin, circulate among them and help them see how events can be dated. One way to help is to point out additional features to be dated. You may need to caution students not to go into too much detail. They should deal with the broader aspects first.

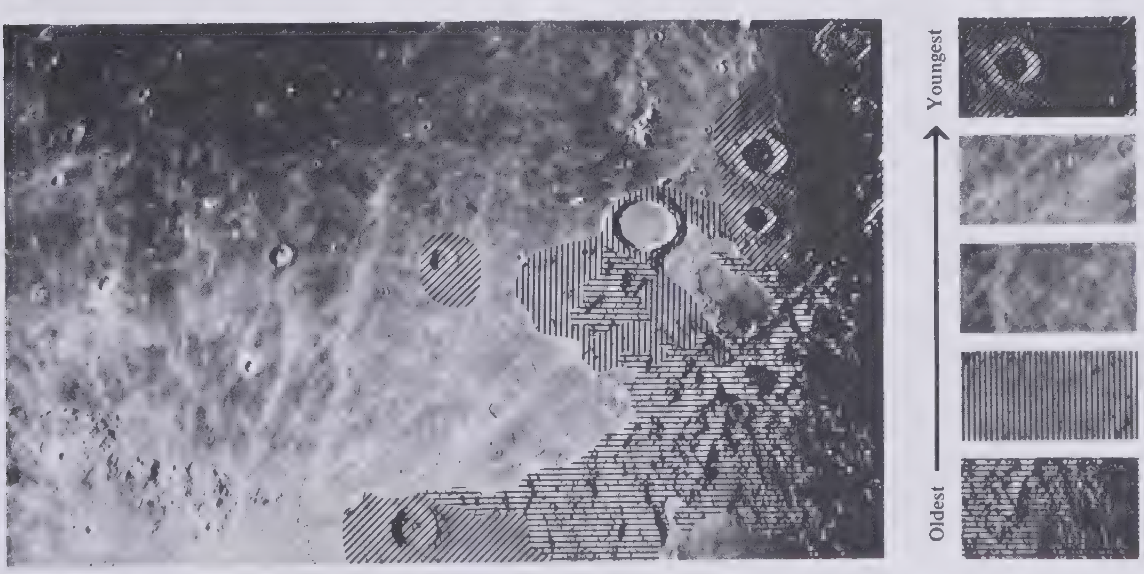
Students may be concerned because they don't know what caused the lunar features. The determination of a sequence of events is valid even if one does not know how various features form.

Ask students to make event maps with a legend showing the last event on the top of the key and the earliest event at the bottom. You might ask students to color the event regions so that they are distinguishable. It will be more convenient for them to compare their results with Guide Figure 19–1 or the geologic map of the moon if you place a copy on the bulletin board.

Range of results

Students should arrive at a sequence something like this: (1) Rays are youngest since they overlie everything. (2) Aristillus, Autolycus, Timocharis, and the small fresh-looking craters have the same relative age. They are formed in mare material, so they must be younger than the mares. (3) Next older is the mare material itself. (4) Next is Archimedes. It is filled with, and hence older than, mare material. (5) Oldest

Guide Figure 19–1
Key to the relative ages of lunar features for Investigation 19–2.



is the basin of Mare Imbrium. If it were not older than Archimedes, its formation would have destroyed or affected Archimedes. The geologic map of this area found in the Teacher's Kit is generalized in Guide Figure 19–1.

The results should vary chiefly in the number of features listed. Some students may list only Archimedes, Aristillus, and the mare material. Be sure to point out that the sequence of events cited on the geologic map is the result of much more refined observations than those the students employed.

Post-lab discussion

In many ways the post-lab discussion is the most important part of this investigation. Questions probably will arise about the relative ages of smaller specific features. Let students work out the sequence of ages if they can. As a last resort you can refer to the geologic map. The legend at the right of the map shows the relative age of features.

Students may ask whether the mare ridges are older or younger than the mare material. If the ridges are anticlines they are clearly younger than the mare material. However, you may point out that the ridges might be the expression of buried topography, just as humps and hollows show through heavy snow. In this case, the ridges are in a sense older than the mare material.

Discussion should bring out the fact that superposition is independent of the origin of features. For example, even if the rays were volcanic deposits, they would still be younger than structures they cover.

The chief limitation of the observation technique used here is resolution. Better photographs might show that superposition relationships are not what they seem from earth.

Answers to questions

1. What seems to be the last feature that formed on the surface? What seems to be the earliest feature? **Answer** Answers to this question will depend a great deal on the students' interpretations of the processes involved. Guide Figure 19–1 shows one interpretation, but students may offer different answers.
2. In what ways did your interpretation differ from the map? In what ways was it similar? **Answer** Students' answers will vary.
3. If you were to land in this area, what five spots would you visit to learn the most about lunar landscape features? **Answer** The spots students list should be areas where the students had the most trouble in determining the relative age relationships. If students picked areas of interest for other reasons you might bring up the problems that were mentioned during the post-lab discussion. Do students think these problems create a need to visit certain areas?

19–3
The evolution of the lunar landscape

This section leaves the relatively firm ground of observation and inference to venture into the quicksands of controversy: How were the craters and maria formed?

There is general agreement that the maria are some sort of volcanic rock. Two schools of thought still exist, however, concerning the evolution of craters. Now that man has been able to travel to the moon's surface and study it more closely, scientists are coming closer to agreement. Most scientists now believe that most lunar landforms come from meteor impact, while the maria and chain craters are of volcanic origin.

Meteor Crater and Copernicus can be compared as follows.

Major similarities:

1. Both are depressions with raised rims.
2. Both are surrounded by deposits of material (ejecta) that clearly has been thrown out of the crater.
3. Both have the same general shape, although in some photographs Meteor Crater has a distinctly square shape, as it appears in Figure 19–14.
4. Both have internal concentric faults, although the faults in Meteor Crater are not apparent on a photograph.

Major differences:

1. Copernicus is far bigger: 92 kilometers in diameter, as compared to Meteor Crater's 1.6 kilometers.
2. Copernicus has rays. Meteor Crater does not, although it might have had a small ray system when it formed.
3. Copernicus has a central peak. Meteor Crater does not. The small mound in the center of Meteor Crater that shows in some photographs is the dump from a shaft sunk in an attempt to find the meteorite.
4. Copernicus has a halo of secondary craters.

Meteor Crater does not. It may once have had secondary craters that have been destroyed by erosion.

5. Meteor Crater has been eroded since its formation, although this may not be apparent in some photographs.

One important cause of the differences listed here is the erosion Meteor Crater has suffered. Meteor Crater probably resembled Copernicus when it first formed some 20,000 to 50,000 years ago. A central peak in Meteor Crater may have been blanketed by freshwater sediment deposition since the crater was formed. However, there is no definite evidence from drilling and geophysical data that a buried central peak actually exists.

We do not understand the origin of central peaks at this time. They may form when material slumps from the sides and crumples up in the center. They may be the result of the earth rebounding from the impact, or of later volcanic activity. The formation of central peaks seems to be related to the size of the crater, since small craters on the moon do not show them. Possibly the absence of a central peak in Meteor Crater is in some way the result of its small size.

If lunar craters are calderas, they should consist of various types of volcanic rock. However, the same rock types may very well be present even if the craters are impact craters. Craters may have been formed by impact in volcanic rock. This possibility could make lunar geological exploration even more complicated. It may be necessary to look for signs of meteoritic impact in volcanic rock. Such signs might be meteorite fragments, melted droplets of nickel-iron, intense shattering, shock melting, and the presence of minerals that form only under high pressure.

Answers to thought and discussion

1. If you were to land on the moon, what kind of samples would you bring back for analysis? **Answer** Students should aim to bring back samples of as many different materials as possible. This would include material from the highlands, maria, and craters. Ejecta or ray material also could provide more conclusive evidence of the formation of these features.
2. How can your knowledge of landscape processes on earth help you understand the development of lunar landscapes? **Answer** The study of earth landscapes provides information about the stage of evolution of a particular landscape. This means you can tell how a landscape has changed in the past and how it probably will change in the future. Such landscape analysis can be applied to the moon once the processes that form lunar landscapes are clearly understood.
3. Explain the effect of the water cycle on sculpturing lunar landscapes. How does erosion occur on the moon? **Answer** The water cycle does not appear to exist on the moon. Temperature and pressure conditions do not allow the moon to retain a significant atmosphere, so there is no medium in which the water cycle can take place. Erosion on the moon is probably the result of gravity acting on materials over long periods of time. Meteoritic bombardment also must play an important role. Intense solar radiation may contribute to mechanical weathering by alternately heating and cooling the moon's surface.
4. The diameter of Copernicus Crater is 92 kilometers and the diameter of Meteor Crater, Arizona, is 1.6 kilometers. Can you find a crater in Figure 19–4 that is the same size as Meteor Crater? **Answer** See Guide Figure 19–2.

GUIDE FIGURE 19–2
The circled crater is the same size as Meteor Crater, Arizona.

19–4
Rock samples from the moon

Meteorites were the only unearthly *objects* scientists had studied before men went to the moon, but students should be able to name several other ways scientists learned about the rest of the universe. Scientists studied, for example, light, radio waves, and other kinds of electromagnetic radiation. How well did this substitute for actual space travel?

The adventure of space travel and its scientific and engineering accomplishments have been emphasized by mass media. Even so, the most direct benefit to most people has been the improved technology, including medical technology, that affects the daily lives of everyone. For example, before men could go to the moon, it was necessary to perfect a small but reliable computer for the spacecraft to take care of the computations required by the various support and guidance systems. Similar computers are now being used in commercial aircraft to keep them on course during bad weather.

19–5
Origin of the moon
19–6
Age of the moon

Information on the age of the moon already has helped scientists better understand the early history of our own planet. Age determinations of the rocks gathered on the Apollo 11 and 12 moon missions have shown that the moon's surface, like the earth's, is not of the same age in every location. Much of the finer material is believed to have been blown out of the highland regions by meteor impact. The oldest rock yet found on the moon is 4.6 billion years old. This is older than any known rock from earth. This date, in fact, is approximately the date for the formation of the earth itself.

Guide Figure 19–3
Decision Form

NAME ______________________

GROUP ______________________

Imagine that you belong to a space crew scheduled to rendezvous with a mother ship on the lighted surface of the moon. However, mechanical difficulties have forced your ship to crash-land 200 miles from the rendezvous point. The rough landing damaged much of the equipment aboard.

Survival depends on reaching the mother ship. Below are listed the 15 items left intact after landing. Your task is to rank them in terms of their importance to your crew in its attempt to reach the rendezvous point, 200 miles away. Place number 1 by the most important item, number 2 by the second most important, and so on through number 15, the least important.

_______ Box of matches

_______ Food concentrate

_______ 50 feet of nylon rope

_______ Parachute silk

_______ Portable heating unit

_______ Two .45 calibre pistols

_______ One case dehydrated milk

_______ Two 100-pound tanks of oxygen

_______ Stellar map of the moon's constellations

_______ First aid kit containing injection needles

_______ Solar powered FM receiver-transmitter.

_______ Five gallons of water

_______ Life raft

_______ Magnetic compass

_______ Signal flares

19–7
"Lost on the moon"

Advance preparation

Reproduce two Decision Forms (Guide Figure 19–3) for each student. Also reproduce twice as many Group Summary Sheets (Guide Figure 19–4) as you have groups. Each group keeps one and hands in the other for scoring.

Time requirements

Pre-lab 5 minutes
Lab 30–45 minutes
Post-lab 10–15 minutes

Materials

The following materials will be needed by each group of five or six students:

- Decision Forms, 2 per student
- Group Summary Sheets, 2

Pre-lab discussion

Introduce the problem without going into details of the exercise. Provide each student with two copies of the Decision Form. Give each group an identifying number or name. Have the students put that number or name on their Decision Forms. Instruct students to work independently, ranking each item in order of its importance.

Guide Figure 19–4
Group Summary Sheet

	Name										GROUP CHOICE
Matches											
Food											
Rope											
Parachute											
Heating unit											
Pistols											
Dry milk											
Oxygen											
Map											
First aid kit											
Radio											
Water											
Life raft											
Compass											
Signal flares											
SCORE											

GROUP SCORE
(average) ______________

When they're finished, students are to record the ranking on both copies of the form.

Ask for two student volunteers to serve as the scoring committee. They will assist you in scoring the forms after they have completed theirs.

Notes on procedure

Students will be full of questions and requests for additional information on almost every item on the list. The only kind of help you should give should be to help the students follow the correct procedure. Simply urge them to make the best selection they can. As students finish, have the scoring committee collect one copy of the Decision Form from each student. The groups should remain separated.

Using the copies of their Decision Forms, students record their individual rankings on a single copy of the Group Summary Sheet.

Meanwhile, have the scoring committee total the individual scores by comparing them with the key in Guide Figure 19–5. For each item, the score is the difference between the student's ranking and the correct ranking. Always subtract the smaller number from the larger number so there won't be negative numbers. The total score is the sum of the scores for each item. The lowest score is the best.

The scoring committee also should compare the average individual score and the range of individual scores for each group. For example, four students in a group have scores of 16, 18, 22, and 24, their average score is 20. The range of individual scores is 16–24.

If you plan to complete the investigation another day, collect the individual and summary forms and return them to the groups at the start of the next class.

Otherwise, ask each group to complete one ranking representing the decision of the whole group. Emphasize that decisions should represent common agreement among group members rather than a simple majority vote. As students try to convince their groups, discussion may become quite animated. Allow plenty of time for groups to reach decisions.

Have the scoring committee collect and score the Group Summary Sheets the same way they did the Decision Forms. The scoring committee also should calculate the difference between

Guide Figure 19–5

Scoring Key

Listed below are the correct rankings for the "Lost on the Moon" Items. The reasons for the rankings were provided by NASA's space-survival unit.

15. Box of matches	Little or no use on moon
4. Food concentrate	Supplies daily food required
6. 50 feet of nylon rope	Useful in tying injured, help in climbing
8. Parachute silk	Shelter against sun
13. Portable heating unit	Useful only if party landed on dark side of moon
11. Two .45 calibre pistols	Useful as self-propulsion devices
12. One case dehydrated milk	Food, mixed with water for drinking
1. Two 100-pound tanks of oxygen	Necessary to breathe
3. Stellar map of the moon's constellations	One of the principal means of finding directions
7. First aid kit containing injection needles	Medicine may be valuable
5. Solar-powered FM receiver-transmitter	Transmits distress signal, location. Possible communication with mother ship
2. Five gallons of water	Replenishes body loss
9. Life raft	Use CO_2 inflating bottles for self-propulsion across chasms, etc.
14. Magnetic compass	Useless because moon probably has no magnetic poles
10. Signal flares	Distress calls, location marker only when within sight.

each group's score and the average individual score for that group's members. The committee then fills in a data sheet for each group listing the following information: average individual score, range, group score, and difference between average individual and group scores. The data sheet in Guide Figure 19–6 can serve as a model.

At this point, if time is available, you can follow a similar procedure with the entire class. A consensus of the class ranking often shows interesting results. Which method of decision-making do students think produces better results: group discussion or voting?

Range of results

The results in Guide Figure 19–7 are from a ninth grade class with average ability. Depending upon your students' background in space science, the results in your classes might vary considerably.

Guide Figure 19–6

Data Sheet

Group	Average individual score	Range	Group score	Difference between average individual & group

Class Consensus Score ______

Highest Individual Score ______

Lowest Individual Score ______

Guide Figure 19–7
Typical class results for Investigation 19–7.

Data Sheet

Group	Average individual score	Range	Group score	Difference between average individual & group
1	41	34-50	24	-17
2	50.5	44-63	36	-18
3	51	22-66	38	-13
4	49.5	44-56	44	-5.5
5	44.6	34-54	28	-17
6	50	44-54	52	+2

Class Consensus Score 22

Highest Individual Score 66

Lowest Individual Score 22

Note that, with one exception, the group score is lower than the individual average score of that group. Also note that the class consensus is much lower than the average group score. This is not unusual. Many factors that were discussed only in one or two groups are brought out in the class discussion. They affect the final decisions of many students.

Post-lab discussion

The following are typical of the kinds of questions you can use to guide the discussion.

1. Did the group score better than any individual? Did it do better than the average individual? Why?
2. Did some group members have more influence than others?
3. How did your group reach agreement? What are the advantages and disadvantages of that method?
4. How did you feel working in the group?
5. What are the advantages and disadvantages of working as a group?

Give each group the final sheet prepared by the scoring committee, return the scored individual forms, and ask the groups to discuss the results separately for ten or fifteen minutes.

After the individual discussions, call students' attention to the chart comparing group results. Have the entire class discuss the differences.

Many points may become evident from the investigation. Often the group that took the longest time to reach its decision will have the best score. Sometimes a usually unresponsive class member will be very resourceful in working out a good ranking.

Answers to thought and discussion

1. Try to find out what kinds of tests scientists are performing on the samples of rock and soil from the moon. **Answer** You might assign this topic as a library research problem.
2. The device invented to monitor the heartbeats of astronauts is now being used to detect future victims of heart attacks. What other devices originally designed for the space program are now being used here on earth? **Answer** Possible answers might be found in such areas as photography, inertial guidance, surveying, and food packaging.
3. Why did scientists want to know the age of the moon? **Answer** Knowing the age of the moon will help answer many questions about both the moon and the earth.

Discussion of unsolved problems

All of the topics discussed in the chapter are rightly considered to be unsolved problems. In addition to the questions raised in the Text there are innumerable other problems about the moon and its history still to be solved.

The possibility that there may be usable natural resources on the moon brings up many questions. For instance, if there are iron deposits on the moon should we mine them? How would we do it? How would we return iron ore to the earth? These questions may have to be answered soon. Rocks on earth that are closely related to some of the moon rocks do contain iron ore. Although no iron ore has been found on the moon, it may be present. (You might mention that some kinds of ores are unlikely to be found there. Ore deposits such as those in the Lake Superior region were produced by the weathering of iron-rich sedimentary rocks. Such deposits almost certainly won't be found on the moon.)

Answers to questions and problems

A

1. How do the moon's seas differ in appearance from the highland areas? **Answer** The maria have fewer large craters, are darker, and are generally smoother than the highlands. They also have domes and mare ridges, which are not found in the highlands. Higher resolution photographs may show the maria to have more craters per unit area than adjacent highlands.
2. What processes that help shape the earth's surface are also active on the moon? **Answer** (1) Volcanic activity is probably the major process common to both bodies. Volcanism is probably responsible for the domes, the mare material, and possibly the large craters. (2) Faulting has visibly affected the moon's surface. It produced many of the radiating features surrounding Mare Imbrium as well as the terraces in large craters. (3) Landslides and possibly soil creep have modified the original features. (4) Meteoritic impact has

produced craters on both the earth and moon, although such craters apparently are less common on the earth.

3. What processes that help shape the earth's surface are not active on the moon? **Answer** All erosional and depositional processes that depend on moving water or wind are absent from the moon. The moon has no appreciable atmosphere and hence no water cycle. Biological activity, including at the moment the work of man, is also absent.

B

1. What is the most widely accepted theory of the origin of the moon? **Answer** The moon probably was formed as a satellite of the growing earth, by the accumulation of dust particles.
2. Why is there no water on the moon's surface? **Answer** If there were free water, astronomers would have seen it by now on Ranger or Lunar Orbiter photographs. Water on the moon's surface would be lost to space quickly in the daylight because of the lack of atmosphere and high temperature. Exposed ice probably would sublimate, although it might survive for a considerable time in permanently shaded regions near the poles. However, some water might exist combined in the structure of various minerals.
3. Why would the moon make an excellent platform for astronomical observations? **Answer** (1) The moon has no appreciable atmosphere. Consequently, instruments on its surface should receive the entire electromagnetic spectrum and cosmic rays without the screening caused by the earth's atmosphere. (2) The shimmering of images caused by atmospheric density fluctuations would be absent. (3) The moon should provide a large, stable platform for mounting sensitive instruments.
4. What does a seismograph placed on the moon's surface tell you about the moon's interior? **Answer** A seismograph told us that the moon is differentiated into internal layers the same way earth is. This information will help scientists to understand the history of the moon.
5. Can you tell relative ages of some of the lunar features by simple telescopic observation? How? **Answer** Yes. In Section 19–2 the students observed crosscutting relationships of lunar features.

C

1. Outline the volcanic theory of lunar crater origin, discussing its weak and strong points. **Answer** The volcanic theory maintains that the craters on the moon are large collapsed volcanoes, or calderas. These features of the lunar landscape appear to be like certain volcanic craters on earth in shape and in composition. The mare material seems to resemble lava or volcanic ash. Glowing pink spots which may be escaping hot gases have been observed. The weak points of the theory are the random location of the craters and the very large size of many of them.
2. Outline the impact theory of lunar crater origin, discussing its weak and strong points. **Answer** The lunar craters could have been formed by the impact of meteorites or comets. This would account for their random locations and for their similarities in appearance to such craters on earth. This theory is questioned because many moon craters are much larger than those on earth. They are far more common on the moon, which is much smaller in size than the earth. Their size and frequency are difficult to explain.
3. What are some of the effects of the moon's low gravitational force? **Answer** The major effect is that the moon can retain no atmosphere. This in turn has had major secondary effects on its geology. In addition, objects fall or slide downhill more slowly. Objects thrown from a volcano or meteoritic impact go higher and farther on the moon. Internal pressure below the moon's surface is about $\frac{1}{6}$ the pressure at the corresponding depth in the earth.
4. Discuss in some detail several reasons why man wanted to journey to the moon. **Answer** Students' answers probably will reflect the search for scientific knowledge, the excitement of adventure, and the possibility of improving earth-bound technology.
5. If you were a scientist studying the moon, what experiments would you have astronauts perform on the surface of the moon? What would you hope you might learn from these experiments? **Answer** You might have astronauts perform seismic experiments, heat flow experiments, solar wind experiments, and lunar atmosphere experiments. You would choose experiments that would tell you more about the lunar surface and interior.

Supplementary Materials

Reference books

Allen, William H. *Dictionary of Technical Terms for Aerospace Use*. NASA SP-7. Government Printing Office, Washington, 1965. Gives precise definitions of many astronomical terms, including most of those applied to the moon.

Baldwin, Ralph B. *A Fundamental Survey of the Moon*. McGraw-Hill Book Company, New York, 1965. (Paperback) Good brief summary of lunar features by one of the leading proponents of the impact theory for crater and circular maria origin.

Baldwin, Ralph B. *The Measure of the Moon*. University of Chicago Press, Chicago, 1963. Detailed exposition of impact theory for formation of lunar surface features.

Clarke, Arthur C. and the editors of *Life*. *Man and Space*. Time-Life Inc., New York, 1968. Good reference on space flight in general, with clear illustrations.

Glasstone, Samuel. *Sourcebook on the Space Sciences*. Van Nostrand Reinhold, New York, 1965. Lucid, chiefly nonmathematical treatment of space science and technology.

Kopal, Zdenek. *The Moon, Our Nearest Celestial Neighbour*. Academic Press, Inc., New York, 1963. Good description of moon's physical characteristics.

Kosofsky, L. J. and Farouk El-Baz. *The Moon as Viewed by Lunar Orbiter*. NASA SP-200, Government Printing Office, Washington, D.C., 1970.

Mutch, Thomas A. *Geology of the Moon. A Stratigraphic View*. Princeton University Press, Princeton, N.J., 1970.

NASA. *Ranger IX Photographs of the Moon*. NASA SP-112, NASA, Washington, D.C., 1966.

——. *Earth Photographs from Gemini VI Through XII*. NASA SP-171, NASA, Washington, D.C., 1968.

——. *Surveyor Program Results*. NASA SP-184, NASA, Washington, D.C., 1969.

Simmons, Gene. *On the Moon with Apollo 15: A Guidebook to Hadley Rille and the Apennine Mountains*. NASA, Washington, D.C., 1971.

Science Year: The World Book Science Annual. Field Enterprises Educational Corporation, Chicago. Summary of the year's developments in science; good source of recent developments in lunar exploration.

Urey, H. C. *The Planets, their Origin and Development*. Yale University Press, New Haven, Conn., 1952.

Periodicals

"Lost on the Moon — A Decision-Making Problem," *Today's Education*. NEA Journal, February 1969.

Films

Universe. 28 minutes, black and white. National Film Board of Canada, 1960. Superior film describing moon, planets, our sun, comets, stars, and galaxies. Excellent narration and highly dramatic animated drawings and photography.

The Lunar Orbiter. 20 minutes, color. NASA. Excellent film describing characteristics of the Orbiter, and problems in getting it launched.

The Moon — Scanning the Universe. Black and white filmstrip. Encyclopaedia Britannica Educational Corp., 1956. Emphasizing lunar phasing.

The Moon. Color filmstrip. McGraw-Hill Text-Films, 1958. See Set No. 1, "The Earth and Its Moon," of *The Story of the Universe* filmstrip series.

Other aids

Maps of the moon can be bought from the U.S. Geological Survey, Washington, D.C. They make superb color displays and good teaching aids. Pitatus Region, I-485 (LAC-94), 1966. Riphaeus Mountains Region, Map I-458 (LAC-76), 1965. Montes Apenninus Region, Map I-463 (LAC-41), 1966. Aristarchus Region, Map I-465 (LAC-39), 1965. Timocharis Region, Map I-462 (LAC-40), 1965. Kepler Region, Map I-355 (LAC-57), 1962.

Topographic Map of the Full Moon (five feet by five feet), U.S. Air Force Cartographic Section, St. Louis, Mo.

20. The Solar System

Chapter Objectives

After completing this chapter, students should be able to:

1. Demonstrate the relative amount of empty space in the solar system compared to the space occupied by the planets.
2. Contrast the characteristics of the two main planet groups.
3. List some physical characteristics of each of the nine planets.
4. Describe how the law of gravitation affects planetary motion.
5. Describe the physical characteristics and motion of asteroids and comets.
6. Contrast the theories of the origin of the solar system.

Teaching the Chapter

This chapter summarizes what the solar system is made of and how it moves. It describes how the gravitational field of the sun directs the motion of the bodies within the solar system through a vast amount of space. You might want to review Chapter 1 briefly to refresh students' concept of measurements in space.

Throughout the chapter other planets are compared with earth. The comparison emphasizes that we live on a planet that in many ways resembles other planets in the solar system.

A portion of the chapter discusses the historical sequence of ideas about the origin of the solar system. These sections offer a fine example of how scientific theories are proposed and then rejected or revised if new information does not support the theory.

Student investigations and actions in this chapter establish that there is a vast amount of empty space within our solar system. Discussions emphasize that gravity can work through all this distance to control the movement of all objects in the solar system.

Suggested time required

It should take five to seven periods to complete the investigations and discuss the topics in this chapter.

Section Notes

20–1
Investigating interplanetary distances

ADVANCE PREPARATION

Calculate the scale distances so you can help students who have trouble with calculations.

TIME REQUIREMENTS

Pre-lab	5 minutes
Lab	20–25 minutes
Post-lab	15 minutes

MATERIALS

The following materials will be needed by each group of two students:

Paper tape, at least 40 m long
Meter stick

SPECIAL NOTES

Space will be a problem since each group is working with 40 meters of tape. The investigation can be done best in a long hall, a gymnasium, or outside the building.

Pre-lab discussion

A good way to begin this investigation is to have the students give their ideas of distances in space. Many students will be able to recite the order of the planets. Some may be able to give their distances from the sun. This does not necessarily mean that they can visualize the distances between planets.

Another question you might ask is: What does the solar system look like from a point in space? Have students discuss their ideas briefly.

Notes on procedure

Once students have studied Figure 20–1 they should select a scale to use for the model. Guide Figure 20–1 shows the measurements students will use if they pick one meter to represent one astronomical unit.

Since the scale diameters of the planets are fractions of a millimeter they will be impossible to plot accurately.

Among the many ways students have used to mark the distances between the planets and the sun are:

1. Mark off the distance with metric surveyor's tape.
2. Measure off the distance using meter sticks.
3. Students may develop some convenient and simple mechanisms to make the measuring easier. One arrangement is shown in Guide Figure 20–2.

Range of results

As long as the relative distances on the paper tapes are reasonably accurate, do not be too concerned about exact measurements. The smallness of the planets in comparison to the distance between them will be obvious when students try to draw a 0.1 millimeter dot on a 40 meter tape.

Post-lab discussion

Now that the scale of the solar system can be seen by the class, you might discuss how long it would take to travel from one point to another. This discussion should clear up any confusion left about the astronomical unit. Students should realize that distances in interplanetary space are unwieldy when you use millions of kilometers.

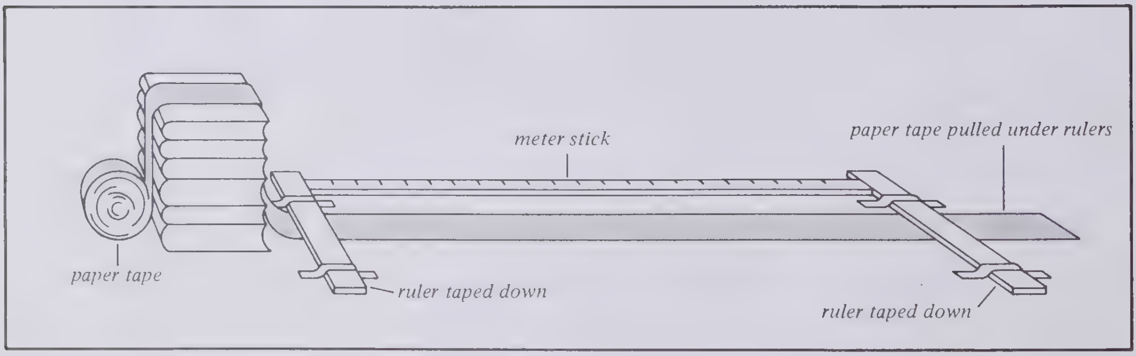
A sample question you might ask is: How long would it take to travel from Earth to Mars at 100,000 kilometers per hour assuming these planets are approximately 0.5 A.U. apart? One half of 150×10^6 is 75×10^6 kilometers. At 100,000 kilometers per hour (a velocity no present spacecraft can reach) it would take 750 hours — about one month.

It would be a rare occurrence to have all the planets line up as shown on the tape. Instead of a tape, a great sheet of paper 80 meters in diameter could be used. Looking at such a large sheet, do you think you could see the planetary dots

Guide Figure 20–1
Solar System to Scale
1 A.U. = 1 Meter

Object	Distance from sun, meters	Diameter, millimeters
sun		11.00
mercury	0.4	0.04
venus	0.7	0.10
earth	1.0	0.10
mars	1.5	0.05
jupiter	5.2	1.12
saturn	9.5	0.95
uranus	19.2	0.37
neptune	30.1	0.35
pluto	39.5	0.05

Guide Figure 20–2
A simple way to measure paper tape for Investigation 20–1.



easily? The solar system seems to be mostly space.

You might point out how close to each other the earth and moon are on the scale model. You can see why interplanetary travel will be a very difficult undertaking. NASA's accomplishment of putting astronauts to the moon meant going only 2½ millimeters on the scale! How far is it to Mars and Jupiter on the model? If the nearest star were added to the model, could you see it? If the star had planets, could you see them at that distance?

Suggested additional activities

Give the distance from the sun for a real or hypothetical asteroid. Have students calculate this distance in astronomical units.

More advanced students could attempt other problems such as:

1. Approximately what portion of the solar system is enclosed by the earth's orbit? **Answer** Total area (πr^2) is approximately $\pi 40^2$ A.U. (39.5 A.U. rounded to 40 A.U.) The earth encloses 1^2 A.U. The relative portion enclosed by the earth's orbit is $1^2/40^2 = 1/1600$.
2. Which planet has the greatest chance of being hit by a meteor? **Answer** Jupiter, for the following reasons: (1) It is the largest planet. Jupiter's cross-sectional area is 100 times that of the earth. Its chance of being hit is 100 times as great. (2) It is close to the belt of asteroids. (3) It has the largest mass and thus the strongest gravitational pull.

20–2
How we learned about the solar system

Action One approach is to have students do this activity before they read the section. Ask them to explain their results using *only* their observations. You can suggest that early men must have felt just as helpless when they tried to explain what they saw in the sky.

20–3
Motions and phases of Planet X

Time requirements

Pre-lab	5 minutes
Lab	10–15 minutes
Post-lab	15–20 minutes

Materials

The following materials will be needed by each group of four students:

- Styrofoam sphere, 3 to 10 centimeters in diameter, stuck on a pencil or a pipe cleaner
- Light source with a 15- or 25-watt bulb

Special notes

Keep the room as dark as possible. You will have to arrange the light sources carefully. If groups are too close together it will be impossible to see the phases of the styrofoam sphere.

There should be no bare wires or terminals exposed on the light sources.

Pre-lab discussion

Begin the investigation by explaining to students that their problem is to produce the phases of Planet X. Should they use a system centered on the earth, the sun, or one centered on Planet X? Do not suggest which arrangement to use. Let students investigate all possible ways to reproduce the given phases.

Notes on procedure

Students should hold the styrofoam sphere in different positions relative to the light. Move about the room, reminding students who are having difficulty that they are trying to find where this planet is relative to the sun and the earth.

If the light source is too diffuse, you will not be able to see the phases.

You get the best results when you close one eye to look at the sphere. You might ask students why they don't see stars and planets in three dimensions.

Range of results

To show all the phases of the moon students should position the sun in the center, with Planet X's orbit between the sun and earth's orbit.

Post-lab discussion

You might have one group present its views and then have a debate. Statements can be made only about information available from the investigation. For example, do not allow a statement such as "But I know that the morning and evening star is really Venus."

Now we can understand what Galileo wrote. Cynthia is one name for the moon and "Mother of Love" refers to Venus, the mythical goddess of love. Galileo secretly announced that Venus showed all the phases of the moon. Therefore, Ptolemy was wrong.

Answers to questions

1. What planet do you believe Planet X represents? **Answer** Either Mercury or Venus is an acceptable answer. Since students should have concluded that this is a planet within the orbit of the earth these are the only choices. They have no evidence to prefer one over the other.
2. Is the orbit of Planet X in the same plane as the earth's orbit? How do you know? **Answer** From the information given, students would have to conclude that it is not. If it were in the same plane we would never see a full or new phase. Infrequently, Planet X does cross the plane of the earth's orbit. However, reasoning exclusively from the model, students would not say so.
3. Are the phases of the moon and of Planet X caused in the same manner? **Answer** No. The main difference in phases shown in Figure 20–6 is the small size of Planet X when it's full and its large size when at crescent. The size of the moon in these phases also varies, but not nearly so much as Planet X. This is because Planet X revolves around the sun in an orbit far from ours. The moon is very close to the earth, so its variation in size is small.
4. If Ptolemy's scheme were correct, could Planet X show all of the phases of the moon? **Answer** Yes. However, the background of stars through which Planet X passed would be different.

20–4
The mechanics of the solar system

Kepler's laws of planetary motion are included in the chapter as topics to be discussed. They are not items to be memorized. Students should be able to see that the first law tells what paths (orbits) the planets follow. The second law tells how they move in orbit. The third law describes how one orbit is related to another.

You might assign the students to do the calculations for Kepler's third law on one or two planets. The results of these calculations are listed in Guide Figure 20–3.

Constructing a time line is an activity that might interest your students. Ask students to look up when Copernicus, Tycho Brahe, Galileo, Johannes Kepler, and Sir Isaac Newton lived. Have them plot their lifetimes on one time line. Students should be able to construct their lines so they have the same information as the time line in Guide Figure 20–4.

These are examples of questions you can ask students about their time lines: Which three astronomers could have made scientific discoveries at the same time? According to the time line it would have been possible for Brahe, Galileo, and Kepler to make scientific discoveries at the same time. What did Galileo invent that made it possible for most of these astronomers to prove their theories? The telescope enabled these astronomers to prove their theories.

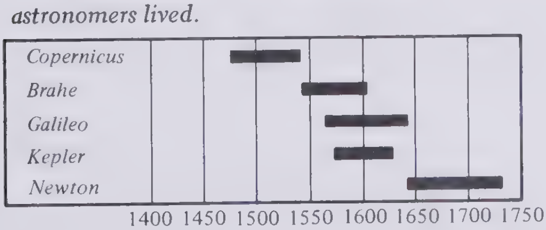
Guide Figure 20–3
Kepler's Third Law Calculations

Planet	Average Distance in A.U.	Average Period in Earth Years	Distance^3 (rounded)	Period^2 (rounded)
mercury	0.4	0.24	0.06	0.06
venus	0.725	0.616	0.38	0.38
earth	1.0	1.0	1.0	1.0
mars	1.52	1.88	3.54	3.54
jupiter	5.2	11.89	141	141
saturn	9.5	29.3	860	860
uranus	19.2	84.0	7,000	7,000
neptune	30.1	164.0	27,000	27,000
pluto	39.45	247.0	61,000	61,000

Answers to thought and discussion

1. Why do you think it was so difficult for the ancients to think of the earth as moving — turning on its axis and circling the sun? **Answer** There were many reasonable-sounding difficulties. When an object moves, it causes air currents. It seemed logical to the ancients, therefore, that if the earth were moving, tremendous air currents or winds would blow continually across the earth. Since this doesn't happen, it seemed much more sensible to believe that the sun was circling the earth. The ancients also reasoned that if the earth were turning on its axis everything would spin off the earth and into space. You can compare the earth to the turntable on a record player. An object placed on the edge of the turntable will be thrown off when the turntable is started.
2. One argument against the turning of the earth was the following. If the earth turns, you should land in a different spot when you jump up off the ground. Why is this argument false? **Answer** As the earth is turning so do you. The same force that is turning the earth is turning you at the same speed. You can show this easily when you are in a bus, train, or plane. If you jump straight up off the floor in a moving bus, for instance, you will land in the same spot. Your body was still moving at the same speed as the bus even when you were in the air, so you came down in the same spot.
3. The retrograde (backing up) motion of the planets was a big puzzle to the ancients. Can you give some examples of retrograde motion one can experience here on earth? **Answer** You can observe retrograde motion when you are running down the street and pass someone who is walking in the same direction. If you look back at the walker, the walker seems to be moving in the opposite direction. Another way to experience retrograde motion is to watch the apparent direction of a car that you are passing on the highway.

Guide Figure 20–4
Time line showing when some famous astronomers lived.



4. Can you think of other ways in which the solar system resembles a clockwork? **Answer** The motions of the solar system can be calculated mathematically with great accuracy. In this way astronomers can predict the phases of the moon, eclipses, and the time it takes the planets to complete one orbit around the sun. The inner workings of a clock can also be calculated with great precision. You can find out exactly how long it takes each gear to rotate once. In this manner you can find out how long it takes the sweep second hand, the minute hand, and the hour hand to go once around the face of the clock.

20–5
Tools for studying the solar system

A field trip to a computer center might be very good here. It would surely point up the speed, accuracy, and tremendous amount of calculations that a computer can make. Colleges, banks, and many types of industry have computer centers that sometimes may be visited.

20–6
Two types of planets

Demonstration This is a way to illustrate the effects of ammonia on living things. Put two plants into large plastic bags. Place a small dish of ammonium nitrate (NH_4NO_3) or ammonium hydroxide crystals (NH_4OH) into one of the bags. Seal both bags with a twist tie.

Have students observe the plants daily. After a few days the plant in the bag with the chemical should be dead.

Ask students why the plant in the bag with the chemical died. As long as students relate the death of the plant to the presence of the chemical in the bag the answer is acceptable. You probably will have to explain the rest of the process. Either of the two chemicals will release ammonia into the air. The ammonia combines with water vapor in the air and the water in the soil to form ammonium hydroxide. It actually is the ammonium hydroxide, a strong base, that kills the plant.

What planets contain large amounts of ammonia gas in their atmosphere? Jupiter and Saturn have large amounts of ammonia gas in their atmospheres.

Do students think that plants like those on earth will be found on Jupiter and Saturn? Plants like those on earth probably will not be found on Jupiter or Saturn. The ammonia in their atmospheres would combine with any available water to form a chemical that would kill the plants.

20–7 The terrestrial planets

One way to approach this section is to assign each terrestrial planet to a group of students. The group is responsible for deciding what observations and measurements an astronaut will make on that planet. Have each group explain its choices.

You might ask students to compare what scientists know about these planets to what science fiction writers have suggested.

The record "War of the Worlds" by Orson Wells on the Audio Rarities label is a simulated newscast of an invasion from Mars. If you play it in class be sure to point out that the people who heard this radio program in 1936 did not hear that it was only a story. Many people believed the invasion really was happening. To tie the record in with this section on the terrestrial planets, you might ask how the story compares to what we know about Mars today. We now know that the atmosphere on Mars is not very similar to Earth's. There is only a very little water vapor in the atmosphere. The temperature on Mars rarely reaches 80°F even at the equator.

You may want to assign interested students to read a science fiction book that deals with life on other planets. Have them compare the book to what we know about the planets. Several of the many possible books are suggested below. *Lucky Starr and Pirates of the Asteroids*, and *Martian Way and Other Stories*, by Isaac Asimov, and *The Martian Chronicles* by Ray Bradbury.

20–8 The major planets

Action This exercise may prove to be nearly impossible if you live near or in a large city. A field trip to a planetarium would be an excellent substitution if city lights make the night sky too bright.

A trip to a planetarium is valuable to any class at this point to stimulate further interest.

20–9 Asteroids
20–10 Comets

If you live where there aren't too many lights at night a meteor shower is a fascinating happening in the sky. If most of your students live in or near a large city, perhaps you could arrange an evening field trip to watch for meteors. Or, you might send a letter home to parents asking them to take a few students from their neighborhood into the countryside for a couple of hours one night.

Below is a list of approximate dates each year when it is possible to observe meteor showers. A day or two before or after each of these dates would still give a good view.

Dates of Maximum Visibility

January 3
April 21
May 4
July 29
August 12
October 12
November 1
November 16
November 17
December 12

Watch your newspaper for the exact dates of these showers each year.

20–11 The origin of the solar system

Demonstration Try to obtain a freely-turning turntable like the ones used by physics teachers to show angular momentum. Have a student stand on the turntable with arms outspread. When the turntable is turning at a medium speed, tell the student to pull his arms close to his chest. Then have the student stretch them out again. Pulling arms in will cause the student to spin faster; sticking them out slows the student down. Be careful to use a *slow* speed on the

turntable until the students know what to expect. *Supervise this activity closely.*

If this demonstration is done properly, students should be able to understand why the theory proposed by Laplace seems to be the most reasonable theory of the origin of the solar system.

Answers to thought and discussion

1. We live on one of the smaller planets that revolves around the sun. Would it be better if we lived on one of the larger ones? **Answer** There are three major reasons why it would not be better for us to live on one of the larger planets. (1) The larger planets are much further from the sun. They are much too cold for man to live without protection. (2) The larger planets have a stronger pull of gravity. A prolonged exposure to intense gravity might harm the human body. It certainly would be hard for people to adapt to an environment where even a chair is too heavy to lift. (3) Because of their greater gravitational pull, these planets have retained the lighter elements in their atmospheres. This means that the atmosphere of the larger planets could not support life as we know it.
2. We live at the bottom of a deep "ocean of air." How does this make it harder for us to learn about the universe? **Answer** The atmosphere makes it harder to learn about the universe because it blurs the visual images we get of the planets and the stars. The atmosphere also prevents high magnification of the objects in space. Students also may suggest that the atmosphere filters out certain wavelengths of radiation that may contain information about other bodies in space.
3. Are the orbits of astronauts as they circle the earth or the moon like the orbits of the moon and planets? Do they obey the same laws of celestial mechanics? **Answer** The orbits of astronauts as they circle the earth or the moon with the engine off are like the orbits of the moon and planets. All bodies in space follow the same laws of celestial mechanics. The laws are based on gravity, not on the size or nature of the body.
4. Suppose you were an astronaut whose mission was to land on Venus. How would your task differ from that of the astronauts who landed on the moon? **Answer** The astronaut whose mission was to land on Venus would have a much longer trip through space. Landing would be much more difficult because Venus has a much greater gravitational pull than the moon. The biggest problem for the astronaut to Venus would be how to carry larger amounts of fuel. The astronaut landing on Venus would need to burn a tremendous amount of fuel to counteract the pull of gravity. The astronaut landing on the moon needs considerably less fuel. The astronaut on Venus would need just about as much fuel to blast off of Venus as it took to blast off from the earth.
5. Why is Pluto grouped with the terrestrial planets rather than the major planets? **Answer** Pluto is grouped with the terrestrial planets because it is small in size and mass like the other terrestrial planets. Pluto's distance from the sun has nothing to do with its classification as a terrestrial planet.

Discussion of unsolved problems

Demonstration You might use the following calculation on the chalkboard to stimulate class discussion about the possibility of other planetary systems. There are approximately 10^{11} stars in our galaxy, and about 10^{10} galaxies. This means there are about 10^{21} stars in the universe. If only 10 per cent of the stars have planet systems, how many planet systems might there be? If planets are formed from material left over after the formation of stars, it seems likely that 10 per cent of the stars would have planets. Do students think life might have developed on one of these other planets?

Answers to questions and problems

A

1. What are the main differences between the terrestrial and the major planets? **Answer** Except for Pluto, the terrestrial planets are closer to the sun than the major planets. The terrestrial planets are small in size and mass compared to the major planets. The major planets with their strong gravitational pulls can hold light gases like hydrogen and helium in their atmospheres.

2. Why are there thousands of small asteroids between the orbits of Mars and Jupiter instead of one large planet? **Answer** There are two theories about the origin of these asteroids. The massive planet Jupiter, with a tremendous gravitation field, may have prevented the formation of a large planet in the space between Mars and Jupiter. Or, an ancient planet once orbiting the sun between Mars and Jupiter may have broken apart. The parts collided again and again to form the asteroid belt we can see in the sky today.
3. How would a massive planet beyond the orbit of Neptune make its presence known to astronomers even if it could not be seen? **Answer** If there were a massive planet beyond the orbit of Neptune it would have a strong gravitational pull. This pull would have an effect on the orbit of Neptune. By measuring the effect on Neptune, astronomers could determine the position and orbit of this planet.

B

1. Discuss the chances that there may be millions of other solar systems in our galaxy. **Answer** Astronomers have determined that there are about 1,000,000,000,000 stars in our galaxy. If planets like those in our solar system existed around one out of every million stars, there would be one million solar systems in our galaxy alone.
2. How would the distance of a planet from its "sun" affect its ability to sustain life? **Answer** The distance a planet is from its sun determines how much light and heat the planet receives. Life as we know it needs heat and light within certain limits to survive.
3. If the earth were ten times as massive as it is, how would life on earth be different? **Answer** If the earth were ten times more massive, life on earth would have to be able to survive in an atmosphere that contained ammonia and other toxic light gases. There also would be a tremendous increase in the amount of gravity. Everything would weigh ten times more. People's legs wouldn't hold them up; plants would fall over. The increased gravity would require a stronger heart to pump blood upward. Such a list could go on and on.

C

1. Suppose an astronomer discovered a planet that took eight years to go around the sun. What would be its distance from the sun? **Answer** Calculated using Kepler's third law, the planet's distance is 4 A.U.

$$P^2 = D^3$$
$$8^2 = 64$$
$$64 = D^3$$
$$4 = D$$

2. The farther from the sun a planet is, the more slowly it moves. Its speed *decreases* as the square root of its distance *increases*. Compare the speed of the earth to the speed of Jupiter. How many times faster does the earth move than does Uranus? **Answer** Using the information from Figure 20–12, Jupiter travels 18 per cent as fast as the earth.

$$\text{Speed} = 1 / \sqrt{30.1}$$
$$= 1 / 5.5$$
$$= 0.18$$

The earth moves about 4½ times faster than Uranus.

$$\text{Speed} = 1 / \sqrt{19.2}$$
$$= 1 / 4.4$$
$$= 0.22$$
$$1 / 0.22 = 4.5$$

3. Large, long-lasting sunspots can be seen rotating with the sun. Such spots make one complete turn about the sun in 27 days. Yet, the sun rotates once in just 25 days. Try to explain this difference. **Answer** One way astronomers have tried to explain this phenomenon is by hypothesizing that the sun is not solid. If this were the case the polar regions of the sun might rotate faster than the equatorial section of the sun, where sunspots are found.
4. A comet and a meteoroid travel at the same speed when in the neighborhood of the earth. Why can a comet be seen for many nights while a meteor appears as just a streak in the

sky, lasting only a few seconds? **Answer** We can see a meteor for only a few seconds while it is being burnt up by friction with the earth's atmosphere. A comet does not pass through the earth's atmosphere. Its light comes from a reaction with the sun. The speed of a comet and a meteoroid does not determine how long they can be seen.

Supplementary Materials

Reference books

Alter, Dinsmore, et al. *Pictorial Astronomy*, 3rd rev. ed. Thomas Crowell, New York, 1969.

Branley, Franklyn M. *The Nine Planets*, rev. ed. Exploring Our Universe series. Thomas Crowell, New York, 1971.

Dexter, William A. *Field Guide to Astronomy Without a Telescope*. Houghton Mifflin Company, Boston, 1971. ESCP Pamphlet Series PS-9.

Hynek, J. Allen and Apfel, Necia. *Astronomy One*. W. A. Benjamin Company, Menlo Park, California, 1972.

Koestler, Arthur. *The Sleepwalkers*. Grosset & Dunlap, Inc., New York, 1963. (Paperback)

Larousse. *Larousse Encyclopedia of Astronomy*, 2nd rev. ed. G. P. Putnam's Sons, New York, 1959.

McLaughlin, Dean B. *Introduction to Astronomy*. Houghton Mifflin Company, Boston, 1961. Excellent general reference for astronomical details.

Moore, Carleton B. *Meteorites*. Houghton Mifflin Company, Boston, 1971. ESCP Pamphlet Series PS-10.

Moore, P. Patrick. *Planets*. W. W. Norton & Company Inc., New York, 1962. Descriptive view of the solar system concentrating on physical characteristics.

Page, Thornton and Page, Lou W. *Wanderers in the Sky*. The Macmillan Company, New York, 1964.

Leonard, Jonathan N. and Sagan, Carl. *The Planets*. Time-Life, Inc., New York, 1972.

Young, Louise B., ed. *Exploring the Universe*. Oxford University Press, New York, 1971. Selections by many authors on the history and philosophy of physical science.

Films

Exploring the Planets. 24 minutes, color. American Geological Institute Films, 1970.

Planets and Comets, Filmstrip from Scanning the Universe series. Encyclopaedia Britannica Educational Corp. Shows configurations of positions of planets, phases of inferior planets, and orbits of comets.

The Solar Family. 11 minutes, color. Encyclopaedia Britannica Educational Corp.

Solar System. 21 minutes, color. International Film Bureau, 1970.

Space Science: Comets, Meteors, and Planetoids. 11 minutes, color. Coronet Films, 1963.

Space Science: The Planets. 16 minutes, color. Coronet Films, 1963.

The Sun and Its Family. Row Peterson Text Films. Filmstrip describing the sun and planets.

Other aids

35 mm slides are available from Mount Wilson and Palomar Observatories and Mount Hamilton Observatory. Send inquiries and requests to California School of Technology, 201 E. Calif. Blvd., Pasadena, Calif.

21. Stars as Other Suns

Chapter Objectives

After completing this chapter, students should be able to:

1. Describe how scientists determine a star's temperature, chemical composition, luminosity, motion, and distance from the earth.
2. Demonstrate parallax and explain how it can be used to measure distance.
3. Compare the sun to other stars.
4. Describe the life cycle of a star.
5. Explain how the mass of a star determines how long it will live.
6. Explain how H-R diagrams support the theory of stellar evolution.

Teaching the Chapter

This chapter is organized around three basic properties of radiation: its direction, quantity, and quality. The chapter emphasizes that we learn about stars by studying their radiation.

The relationship of the sun to other stars is stressed throughout this chapter. Other stars are compared to the sun in terms of mass, luminosity, size, density, temperature, and chemical composition. Students find that unlike the sun, many stars are members of double or multiple star systems.

Students make simple Hertzsprung-Russell diagrams for several stars to picture the relationship between luminosity and temperature. This diagram lays the groundwork for examining stellar evolution.

Suggested time required

It should take four to six periods for students to discuss the topics and complete the activities in this chapter.

21–1
Measuring starlight

It is important that students understand, what properties of starlight can be analyzed.

Demonstration You might illustrate the *quantity* of light by comparing a 10-watt light bulb to a 50-watt bulb. With a simple dimmer switch, you can dim the bulbs so that they give off a yellowish light. This yellow *quality* of the light then can be compared to the white light from an undimmed bulb. The *direction* of light can be shown by asking students to compare the direction a shadow cast by the sun points in the morning to the direction it points in the late afternoon.

21–2
The distance to the stars

Action Students should get the greatest shift in apparent position of the lamp against the wall when they are closest to the lamp.

Can any students suggest more common examples of parallax? Human vision is the most obvious illustration of parallax. Each eye sees a slightly different view of the world. The brain analyses the differences in the pictures to help determine depth and distance. Human eyes are about four inches apart. You can explain that the way astronomers use parallax is equivalent to placing one eye at each side of the earth's orbit. Transparencies of Guide Figures 21–1 and 21–2 may help you explain how this works. The farther away a star is, the smaller angle P be-

comes. For very distant stars the sight lines are close to parallel.

Action Since the rocket is travelling at 300,000 kilometers per hour and light travels at 300,000 kilometers per second, the rocket would take 3600 times longer to reach the star than the light would. Light from Proxima Centauri takes 4.3 years to reach earth. Multiplying 3600 × 4.3 years gives 15,480 years. It is clear that it would not be possible to make the journey in one lifetime.

21–3
The stars move in space.

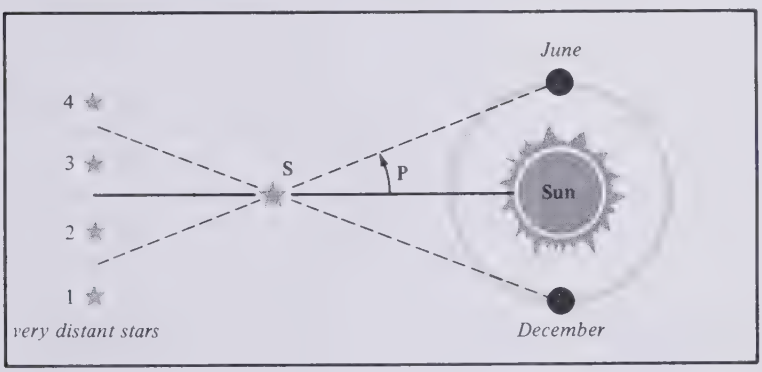
Students might be interested in learning more about the constellations. You could assign each student a constellation to research. The mythology behind the constellation names is fascinating. The students' reports will make a good change of pace for discussion. Another student might report on the "signs of the Zodiac" and the mythology of astrology.

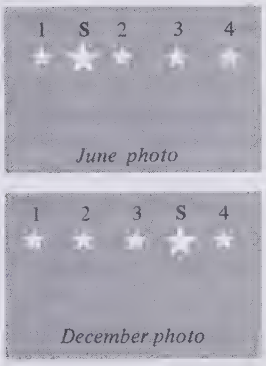
It is important that students realize that *every* object in the sky is moving. One good way to help students with this concept is to ask students to name something in the sky that does not move. If anyone names some objects, let other students cite evidence that these objects are moving.

21–4
The masses of the stars

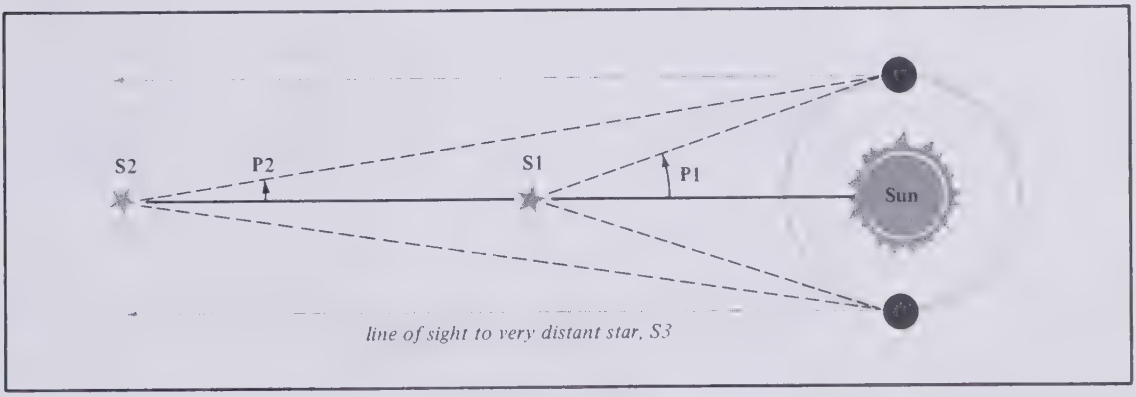
A useful example when you discuss measuring the masses of stars is a seesaw with an adult on one end and a child on the other. The adult must sit much closer to the fulcrum to balance the seesaw. This example applies directly to binary stars. The lighter and less massive a star is, the further out it swings from its companion as both of them turn about their common center of mass.

Guide Figure 21–1
Parallax changes the place in the sky where we see a nearby star.





Guide Figure 21–2
Parallax is less obvious for distant stars. They have no measurable parallax.



21–5
The brightness of stars

Action This activity enables students to construct their own magnitude scale to measure the brightness of stars. Have students compare other stars in Figure 21–5 to the scale constructed from the Little Dipper.

It might be interesting to have students compare their results to the results they think early man might have gotten. What might be different now?

Encourage students to try this action on their own some night. You might expand the activity by asking students to use their Little Dipper Magnitude Scale to measure the brightness (luminosity) of the stars in a constellation you assign. A constellation chart will help students identify the assigned area of the sky.

You can use other examples to help students become familiar with the mass-luminosity law for stars. What would happen, for instance, if the sun were four times as massive as it is now? (Assume the surface temperature remains unchanged.) If the sun were four times as massive, it would be about 64 times brighter than it is. It would use up its fuel 64 times faster. What would happen if the sun were 10 times as massive? If the sun were 10 times more massive, it would be about 1000 times brighter than it is now. It would use up its fuel about 1000 times faster as well.

21–6
Some stars' brightness varies.

Students may have difficulty understanding eclipsing variable stars. You can explain that they are double stars whose orbital plane lines up with the earth. Earth observers can see the two stars eclipse each other. If our solar system were moved to another location, earth observers would have a new point of view. Some of the double-star systems would no longer eclipse.

Demonstration You can make a demonstration model of an eclipsing binary system by mounting two electrical sockets at opposite edges of a round piece of wood. Put two bulbs that are the same size in the sockets. You can demonstrate eclipses by turning the wooden circle like a wheel around a nail at its center.

One way to emphasize the importance of the Cepheid method for working out distances to the stars is to refer to the parallax method of getting star distances. In Section 21–2 students saw little or no change in the apparent position of the bulb when it was far away from them. Likewise, the Cepheid method lets astronomers measure distances to stars so far away that parallax is insignificant.

Answers to thought and discussion

1. All stars except the sun appear only as bright but unmagnified points of light even in the greatest telescopes. How then is it possible to obtain information about these stars (their distances, sizes, luminosity)? **Answer** The distance to a star can be found by using the parallax method or the Cepheid method of calculating distances. The parallax method measures a star's apparent shift of position against the background of more distant stars when it is seen from the opposite sides of the earth's orbit. The actual distance of the star can be calculated by measuring the amount of shift and knowing the distance across the earth's orbit. This method only works for nearer stars. The Cepheid method can be used wherever a type of star called a Cepheid variable can be found. Even very great distances can be measured using this method. The apparent magnitude and the absolute magnitude of the star can be determined by measuring how long it takes the star to fade and brighten. With both magnitudes, you can also calculate the star's distance.
2. Give some examples of the parallax principle from everyday life (e.g., looking at a close object first with one eye, then with the other). **Answer** Many examples can be mentioned. Anyone who has tried to thread a needle, for instance, has faced a parallax problem. The thread appears to jump out of line if you look first with one eye, then the other. Students may suggest the situation in Investigation 14–2 where they traced contour lines on the transparent sheet. To get the lines in

the correct position, students had to keep their eyes at the same angle to the model.

3. Nearly all of the stars that are closest to the sun are invisible to the unaided eye. How is this possible? **Answer** Most of the stars closest to the sun are small, cooler stars of low luminosity. The amount of energy they transmit is so small that we need a telescope to see them at all.

21–7
Colors and stellar temperatures
21–8
What stars are made of

Demonstration You can demonstrate the relationship between color and temperature to students. Clamp an iron rod to a ring stand. Ask students what colors they will see when the iron is heated. In what order will the colors appear? Use a blow torch, if possible, to heat the iron rod slowly. Students should be able to see the rod turn to a bright red color. If you have a powerful enough torch the rod will fade slowly to nearly white. Be sure to use proper safety precautions for yourself and the class.

Point out to students that regardless of the composition of a glowing substance, the continuous spectrum is the same. (See Figure 21–9.) In other words, the pattern from red to yellow to green to blue is the same for all elements. It is the positions of the lines in the bright- and dark-line spectra that depends upon the specific atoms involved. Each type of atom, hydrogen, for example, has a set of lines that is different from that of any other type of atom. The Text refers to these unique lines as the fingerprints of the chemical elements. The position of these lines in the spectrum of a star identifies the chemical elements present.

You might suggest to interested students that they read about Niels Bohr. They should be able to find an explanation of why spectral lines are unique for each element.

Demonstration Students can observe and compare spectral lines for themselves with the Spectroscope Kits. Let students practice using the spectroscope by looking at the sky (*not* directly at the sun).

Different spectra can be observed from different light sources. Students may be interested in comparing light from incandescent bulbs, fluorescent bulbs, matches, or any other light sources. If you have filters or colored cellophane students can see what effect they have on the spectra.

You might expand this activity by having students draw the spectra they observe.

Students may resist the idea that stars are of different colors. To many casual observers, all stars are white — period. You might remind students that the tools scientists use can detect color differences human eyes can't see.

A good illustration at this point is to assemble a variety of paint chips for different shades of white. When students look at the chips from across the room they may not be able to detect the differences among them. A closer look will establish that the whites are not identical.

21–9
The H-R diagram of stars

Action If you think your students will have difficulty you can help set up the graph. You could, for instance, draw an H-R diagram with only the scales on it on the chalkboard or an overhead transparency. Then direct the students to plot the information from Appendix F.

Four sheets of five millimeter grid graph paper taped together work well for plotting this H-R diagram. This allows the 11 logarithmic luminosity and eight temperature (stellar class) divisions to fit exactly within the edges of the paper. The graph paper only approximates the logarithmic scale for luminosity but the results are close enough so that you need not use semilog paper.

When it's complete, the graph should resemble Figure 21–11.

What pattern do the stars form? Most of the stars form a nearly-straight line from the upper left of the graph paper to the lower right. Do the positions of the brightest stars and the nearest stars differ? The brightest stars tend to be in the upper left quarter of the graph. Most of the nearest stars are in the lower right quarter of the graph. Is the sun more or less luminous than most of the other stars in the diagram? Is it hotter or cooler than most?

The sun is plotted in the middle of the H-R diagram. At first glance, the expected answer is that the sun is average in both respects. However, further discussion should bring out that in relation to the more common stars in the galaxy (those of the type of the 20 closest stars) the sun tends to be hotter and more luminous. In comparison to the stars that can be observed at night with the unaided eye (the 20 brightest stars) the sun is actually cooler and less luminous. Most of the students have always been told that the sun is an average star. This is true only in the context of the H-R diagram. Compared to a truly average star in our galaxy, the sun must be rated as somewhat special.

21–10
The life of stars

This is a good time in the chapter to refresh students' familiarity with the mass-luminosity law mentioned in Section 21–5. After they discuss this section you could challenge them with the following problem: If a star were twice as massive as the sun, what could you tell about its life span? If a star were twice as massive as the sun, it would be eight times brighter than the sun, according to the mass-luminosity law. It would use up its fuel eight times faster than would the sun. Since this star has twice as much fuel as the sun but uses it eight times faster, its life expectancy would be ¼ that of the sun.

Questions may arise about white dwarfs, neutron stars, and black holes. These frequently are discussed in newspaper and magazine science articles. All three phenomena have to do with the last stages of a star's life. The form a star takes in its final stage is determined by its original mass. Stars about as massive as the sun will become white dwarfs; stars somewhat more massive will become neutron stars; still more massive stars will become black holes.

Very simply, the difference among them can be stated this way. In a white dwarf the matter is very densely packed, but it is not so dense that the protons and electrons lose their identities. In a neutron star the matter becomes so densely packed that the electrons and the nucleus of the atoms are crushed together into one large ball of nuclear fluid. In the case of a black hole matter becomes so compressed, and the radius of the star so small, that the star's surface gravity is high enough to warp the space and time around the star. Light from the star merely circles the star instead of traveling out into space.

21–11
Star dust

Discussion should make clear to students that the interstellar matter described as dust is very different from household dust. Interstellar dust particles most probably are frozen compounds of hydrogen. Each particle is smaller than 1/1000 millimeter in diameter.

Encourage students to go outside and look into the night sky. Using the star charts in the Appendix of the Text, they can identify many of the various objects in the sky. They should look for planets, stars, double stars, meteorites, and the Orion Nebula.

Answers to thought and discussion

1. What are the differences between galaxies and nebulae? **Answer** A galaxy is a huge system of stars lying far out in space. A nebula is a cloud of dust and gas that is a part of a galaxy.
2. If two stars were formed at the same time, but one was more massive than the other, which one would shine longer? Which of them would be brighter? **Answer** According to the mass-luminosity law, the more massive a star is, the brighter it shines and the more fuel it burns. Therefore, the smaller of the two stars would shine longer. The larger star would be brighter.

Discussion of unsolved problems

Scientists trying to unravel the secrets of a star's life have turned light into a time machine. Light's speed — just about instantaneous at earthly distances — takes a long time to travel the distances between stars and the earth. When scientists look for distant stars they can see into the past. They look for clues to the conditions and events at the birth of a star or a solar system.

Students may want to discuss how life would be different if light travelled so slowly that we could see into the past here on earth.

Answers to questions and problems

A

1. Star A is twice as massive as star B. Which one will have the longer lifetime? Which one will be hotter? **Answer** Star B will have the longer lifetime. Star A will be hotter.
2. How many kilometers per hour does light travel? **Answer** Light travels at 300,000 kilometers per second. Since there are 3600 seconds in one hour, light travels at 1,080,000,000 kilometers per hour ($3600 \times 300{,}000$).
3. Why does the direct parallax method work only with relatively nearby stars? **Answer** As a star gets more and more distant, the less it seems to change its position as you look at it from the opposite ends of the earth's orbit. Beyond a certain distance the star is so far away that its position change is about equal to the amount of possible error in the calculations. Under these circumstances it is useless to try to calculate the distance of stars that are very far away using parallax.
4. In what two ways can the temperature of a star be determined? **Answer** A star's temperature can be read in its starlight. The spectrum of a hot star is much richer in blue light than it is in red light. The opposite is true of a cool star. The lines in the spectrum of a star give us another way of getting the star's temperature. We know from laboratory studies at what temperatures certain spectral lines of a given element appear most prominently. Thus, when we see those lines in the spectrum of a star, we know two things. We know that the star contains that chemical element. We also know the temperature of the star's surface.
5. Discuss the sun's position on the H-R diagram. **Answer** The sun is positioned in the center of the H-R diagram. This position indicates that the sun is an average star. It also indicates that the sun is at its prime of life in relation to the theory of stellar evolution.

B

1. Why do you think that astronomers call our sun an average star? **Answer** Astronomers call the sun an average star because the sun falls into the main sequence stars on the H-R diagram. This tells us that the sun's temperature and luminosity are within the ranges of temperatures and luminosities of other stars.
2. Why can't a telescope magnify a star? How can we see many more stars through a telescope than with the eye alone? **Answer** The sun is the only star with a surface we can see and telescopes can magnify. Other stars are just too far away to be magnified. Large telescopes, however, gather much more light than the eye alone can. The larger the telescope, the more stars that can be seen and photographed.
3. Why will the constellations not look the same many thousands of years from now? **Answer** Astronomers have determined that to a greater or lesser degree all stars have proper motion. This means that as the stars move in space, their positions in the constellations will change.
4. If a star is moving directly toward us, will it show any proper motion? radial velocity? **Answer** If a star is moving directly toward us, it will not show any proper motion. This is because astronomers measure proper motion by measuring a star's change of position with respect to the other stars in the sky. A star that is moving directly toward us will show radial velocity. Astronomers measure a star's radial velocity by using the Doppler effect.
5. Why does a star have to be a member of a double star system before we can determine its mass directly? **Answer** The masses of both stars in the system can be found from their gravitational effects on each other. The gravitational pull of each changes the path of the other star from what it would be as a single star. A single star is too far away from other stars for its mass to change another star's path enough to measure.

C

1. Why is it that a photograph can show us more than we would see by just looking through the same telescope used in making the photograph? **Answer** By using a timed exposure, a photograph can pick up very faint points of light that would not be visible to the naked eye looking through the telescope. Also, a photograph can capture on film an event that might happen very quickly. This way the event can be studied carefully.

2. Suppose that a star that is 10 light years away has a planet with an advanced civilization. If we should happen to hear a radio program from that planet, how long ago would that program have been broadcast? **Answer** The program would have been broadcast 10 years ago. Radio frequencies travel at the same speed as light.
3. Two Cepheid variable stars appear equally bright in the sky. One of them has a much longer period than the other. Which one is farther away? **Answer** The star with the longer period would have a greater absolute magnitude than the star with the shorter period. Therefore, the star with the longer period must be farther away for both stars to appear equally bright.
4. A star of the 1st magnitude is exactly 100 times brighter than a 6th magnitude star. A 6th magnitude star is 100 times as bright as an 11th magnitude star. How many times brighter is a first magnitude star than an 11th magnitude star? The faintest stars that can be seen through a telescope are about the 23rd magnitude. How many times fainter are these stars than stars of the 18th magnitude? than stars of the 13th magnitude? **Answer** A 1st magnitude star is 10,000 times brighter than an 11th magnitude star. Stars of the 23rd magnitude are 100 times fainter than stars of the 18th magnitude. Stars of the 23rd magnitude are 10,000 times fainter than stars of the 13th magnitude.

Supplementary Materials

Reference books

Alter, Dinsmore et al. *Pictorial Astronomy*, 3rd rev. ed. Thomas Crowell, New York, 1965.

Bergamini, David and the editors of *Life*. *The Universe*. Time-Life, Inc., New York, 1969.

Branley, Franklyn. *The Sun: Star Number One*. Thomas Crowell, New York, 1964.

Dexter, William. *Field Guide to Astronomy Without a Telescope*. ESCP-PS-9, Houghton Mifflin Company, Boston, 1971.

Land, Barbara. *The Telescope Makers: From Galileo to the Space Age*. Thomas Crowell, New York, 1969.

Periodicals

Federer, Charles A., ed. *Sky and Telescope*. Sky Publishing Corporation, Cambridge, Mass.

Films

The Story of Palomar. 40 minutes, color, Encyclopaedia Britannica Educational Corp. Covers telescopes and general astronomy.

Universe. 28 minutes, black and white. The National Film Board of Canada. Fine film on general astronomy.

22. Galaxies and the Universe

Chapter Objectives

After completing this chapter, students should be able to:

1. Describe the Milky Way galaxy — its size, shape, rotation, and the sun's location in it — and indicate how scientists obtained this information.
2. Compare our Milky Way galaxy to other galaxies in terms of size and shape.
3. Explain why looking at starlight is like look-into the past.
4. Name the two most common chemicals in the universe.
5. Discuss the significance of the Doppler effect as evidence for an expanding universe.
6. Discuss common examples of relativity.

Teaching the Chapter

Since this is the last chapter of the book, the class may be behind schedule when you arrive at this point in the course. If you have only a day or two available, the chapter still can be used to sum up the thrust of the entire course. If you have time for little else, discuss the place of the earth in the galaxy and the relation of our galaxy to other galaxies.

Emphasize that there is at least one place in the universe that the transformation of matter into energy has gone into the creation and maintenance of a climate favorable to life. Two things should follow from this: it is highly improbable that the earth represents the only location in the universe favorable to life and secondly, the time scale of the sun's existence indicates that the earth's climate will be favorable to life for several billions of years to come.

By the end of this course students should recognize that humanity is confined to the earth for all practical purposes. Students should discuss how long our space vehicle will remain habitable.

A description of the different types of galaxies and their distribution in the neighborhood of our galaxy is followed by a section on time and relativity. The closing sections of the chapter deal with the structure and origin of the universe as a whole.

The first investigation firms up the students' awareness of the component parts of the universe. It dramatizes the vast amount of space in the universe. In the second investigation students classify galaxies by their appearance and arrange them in an evolutionary sequence.

This chapter encourages philosophical questions, so many class discussions will not reach any answer. The Text points out that science can only tell what and how — it cannot tell why. The historical approach to scientific discoveries illustrates the short interval of time during which man has understood the mechanics of the solar system.

Suggested time required

It should take four to six periods to discuss the topics and complete the investigations in this chapter.

Section Notes

22–1
The earth in the Milky Way

Demonstration You can illustrate with a large newspaper photograph how the stars in the Milky Way blend together into a white band. Pictures in almost any newspaper are made of thousands of tiny black dots. Hold up a picture and ask students to write down as many observa-

tions as they can. (Make sure the students observe the picture from a distance.) When the students have finished, tell them that you are looking for one specific observation. Write your observation — "made up of many tiny dots" — on a piece of paper. Start on one side of the room and ask each student to contribute one observation that is different from those preceding students have given. When no new observations are being made, circulate the picture around the room. Ask students to make one further observation about the picture. Several students should observe the black dots. If none of the students make this observation, ask what the picture is made up of. Students should be able to draw a comparison between the picture and the Milky Way. Looking at the picture from a distance is like looking at the Milky Way with the naked eye. Looking at the picture up close is like looking through a telescope.

22–2
Other galaxies

The following activity should help make it clear to students how we learn about our galaxy by looking at other galaxies. Tell students to imagine that they are riding down the highway in a car. The car windows are rolled up and the doors are locked. What can the students tell about their car? From what they can see on the other cars, students probably will assume that their car has four tires, two or four headlights, two tail lights, some type of grille in front of the car, directional or turn signals, and bumpers.

22–3
Deep Sky Watch

Because it must be done at night you might want to assign this investigation as an optional or extra credit project. The Earth Science Curriculum Project pamphlet *Field Guide to Astronomy Without a Telescope*, listed in Supplementary Materials, is a good reference for this investigation.

Answers to thought and discussion

1. Do you think it would be much different if we lived in another galaxy? **Answer** If we lived in another galaxy conditions on earth probably would be the same as they are now. The only thing that would change would be the stars and galaxies we would see in the sky.
2. If the sun moved on an orbit that was much closer to the center of the galaxy, would we still see the Big Dipper? Saturn? the Milky Way? **Answer** Some of the stars in the Big Dipper might be blocked from our view by dust and clouds within our galaxy. Even if we still could see all the stars in the Big Dipper, we probably would see them from a different angle. They would form a completely different pattern. Since the sun would take the planets with it to its new position, we would still be able to see Saturn. If the sun moved on an orbit closer to the center of the galaxy, we could see more of the Milky Way.
3. What events were taking place on earth when the light you see tonight from Arcturus and Spica left those stars? **Answer** Students' answers will depend upon their background in history. Light from Arcturus left there 36 years ago. Students may be able to coordinate this date with an event in their family, a parent's birthdate, for example. Others may mention the final years of the Great Depression and the rise of Hitler to power in Germany.

   Light from Spica left there 212 years ago. This date ties in, for example, with the events surrounding the American Revolution.

22–4
The size of the universe

A good way to begin this section is to show the movie *Cosmic Zoom*, listed in Supplementary Materials. Student discussion of the material in this section can take many directions, but most of it will fall in the range of philosophy. We know very little about the boundary of the universe, if it has any.

Demonstration A Möbius strip is a device that often helps students visualize what scientists mean when they describe something as unbounded or endless. Have students take a piece of paper about 45 centimeters by 2 centimeters and lay it flat on the desktop. Bring the ends together to make a ring, but before you tape the ends together, give one end a half-twist.

Ask each student to make a pencil dot somewhere on the loop halfway between the edges. Now have students draw a line along the strip

beginning at the dot. Where does the line end up? How many sides does the strip have? How would you describe the universe if it were shaped like this?

22–5
Our place in the universe

When you discuss the cosmic navigator in search of planet earth, be sure to ask students to point out the problems the navigator would have. This discussion should compare the size of planet earth to the size of the universe.

22–6
Classifying galaxies

Advance preparation

Make sure that each set of galaxy photographs shows nine different galaxies. The nine types of galaxies are shown in Guide Figure 22–1.

Time requirements

Pre-lab	5 minutes
Lab	10 minutes
Post-lab	10–15 minutes

Guide Figure 22–1
The nine galaxies in the Galaxy Card Kit.

Materials

The following materials will be needed by each group of two or three students:

- Galaxy Card Kit or photographs of different galaxies

Pre-lab discussion

Pass out the galaxy cards. One way to help students understand what they are expected to do in this investigation is to ask questions. You might ask, for example, if there are other types of galaxies. How do other galaxies compare to the Milky Way? Might they be related to one another in an evolutionary sequence?

Notes on procedure

As students work, you can circulate among them and look for students who seem stalled. Sometimes a student will be helped if you ask a specific question. For example, what makes this galaxy different from the Milky Way? Are any others like it?

The galaxies range from tight spherical clusters, through various degrees of spiraling, to seemingly unstructured nebulas. Students may choose to classify according to the orderliness of the galaxy or by the degree to which it has developed spiral arms. There are also other good bases for classifying the galaxies. For example, more observant students may notice that the centers of some galaxies are elongated or barred rather than spherical. This may lead them to a subclassification of barred spiral galaxies.

You should look for a logical classification system rather than a "right" answer. There is no correct answer.

Range of results

Normal spirals, barred spirals, and irregulars may become mixed in some cases. Elliptical galaxies generally are easy to recognize at any angle because of the diffuse halo of stars surrounding them.

Post-lab discussion

Let students discuss their systems for classifying the galaxies. They may discover and correct inconsistencies in their own systems as they go.

One of the most widely used systems of classifying galaxies was proposed by Edwin Hubble in the 1920's. It is illustrated in Guide Figure 22–2. You can draw it on the chalkboard. His three principal types are spirals, barred spirals, and ellipticals. Spirals and barred spirals are designated by S and SB respectively. Lower case letters a, b, and c are added to indicate how tightly the arms are coiled. Thus Sa is a normal spiral with tightly wound arms, and SBc is a barred spiral with open arms. Elliptical galaxies are designated with the letter E, followed by a number that indicates the degree of ellipticity. Spherical galaxies in this system are labelled EO. Highly flattened ellipticals are type E7. Galaxies

Guide Figure 22–2
A common system for classifying the development of galaxies. The series might go in either direction.

classified as SO have the disk shape of spirals, but show no trace of spiral arms.

When the discussion turns to the relative age of the galaxies, students may become as embroiled in debate as astronomers are. Guide Figure 22–2 shows the arrangement most commonly agreed on, but the direction of increasing age is still controversial. Some astronomers believe that a globular cluster spins out into spiral arms and eventually becomes an unstructured mass of stars. An opposing school of thought maintains that galaxies start as shapeless clouds and, as stars evolve in the outer reaches, the cloud gradually becomes more spherical.

ANSWERS TO QUESTIONS

1. Can you fit the spiral and elliptical galaxies into one sequence? **Answer** Yes. They will fit into many different sequences, depending on the student's point of view.
2. Do the spirals and the ellipticals by themselves form a meaningful sequence? **Answer** Students may find many defensible systems of sequence.
3. On what characteristics did you base your system of classification? **Answer** Most students will indicate the shape of the galaxy. A few will compare the apparent density of each galaxy. However, there is no single correct answer to the question.
4. Does the sequence of galaxies you constructed suggest that one type of galaxy might have evolved from another? If so, which types would you consider the youngest and the oldest? **Answer** Since dust and gas are the stuff from which stars are born, galaxies without dust and gas presumably cannot undergo any more star formation. Such galaxies may therefore be in a more advanced stage of evolution than galaxies that still have dust and gas.

22–7
The red shift

Action You may find it necessary to put the axes from Guide Figure 22–3 on the board if students have trouble setting up their graphs. When students have graphed the data, you might ask them to find the ratio of kilometers per second/million light years for several galaxies. The ratios should cluster around 30 kilometers per second/million light years. If ratios on a graph are nearly the same for all the examples, you are dealing with a constant. To illustrate how astronomers use this constant you might ask: If you observed a galaxy that had never been seen before and found its velocity to be 48,000 kilometers per second, how far away would it be? Some of the students should realize that they can locate 48,000 kilometers per second on their graph and read down the graph to find the distance of 1,500 million light years.

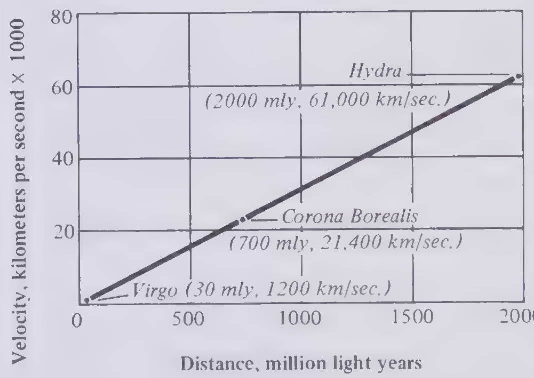
What does the accuracy of your distance determination depend on? The accuracy of the distance depends on how accurately you calculated the speed of recession of the galaxy needed to produce the observed red shift. If the distances of some galaxies had not been determined independently, could you use the red shift to determine distances? Unless the determination of the distance of some galaxies had been done independently, Hubble (or any other astronomer) would not have had enough data to show the relationship between the speed of a receding galaxy and its distance.

Does the velocity-distance relation suggest that we are at the center of the universe? Since the velocity-distance relationship tells us that all the observable galaxies are moving away from us, it would seem logical to assume that we are at the center of the universe. Does your graph show a straight or a curved line? The graph shows a straight line. Any constant should produce a straight line when it is graphed.

Answers to thought and discussion

1. Think of earth as a spaceship. How does it get its supplies? How does it manage to carry enough air for its passengers to breathe? How does it get rid of waste materials? **Answer** The

GUIDE FIGURE 22–3
Graph of the red shift for the Action in Section 22–7.



earth gets its supplies from the energy of the sun. Using the sun's energy the earth produces food for its passengers. Gravity holds the gases in the atmosphere close to the earth as it travels in space. The earth recycles its waste materials. Plants give off enough oxygen to keep animal life going and at the same time use the carbon dioxide given off by animals.

2. What are the most powerful methods of gauging the distances to galaxies? **Answer** The two most powerful methods of gauging the distances to galaxies are the Cepheid Variable method and the red shift or Hubble's constant method.
3. Can you think of another possible reason for the red shift other than the actual motion of galaxies away from us? **Answer** Another possible reason for the red shift could be that we are moving away from the other galaxies. This motion would also produce a red shift.
4. What would it mean if some distant galaxies were found to have a blue shift instead of a red shift? Discuss the consequences of such a discovery. **Answer** A blue shift would mean that these distant galaxies would be moving toward us. A discovery of this kind would, first of all, cast doubt on the red shift method of calculating the distances of galaxies. Even more important, however, is the impact this discovery would have on the theory of an expanding universe. So far, all observations of the galaxies have supported this theory. But even one galaxy moving toward us would seriously jeopardize its validity.

22–8
Measurements are relative.

If your students have trouble understanding the relativity of measurements, you might want to use this additional problem to help clarify the idea. Imagine a girl inside a train running at a speed of five miles per hour towards the front of the train. The train, meanwhile, is traveling at a speed of 60 miles per hour.

Meanwhile, a boy is standing on the ground outside watching the girl and the train. At what speed does the boy see the train moving? 60 miles per hour. How fast does the boy see the girl moving? 65 miles per hour. Does it matter whether you measure the girl's speed from the train or the ground? Yes, her speed depends on the place from which you take the measurement.

22–9
Relativity

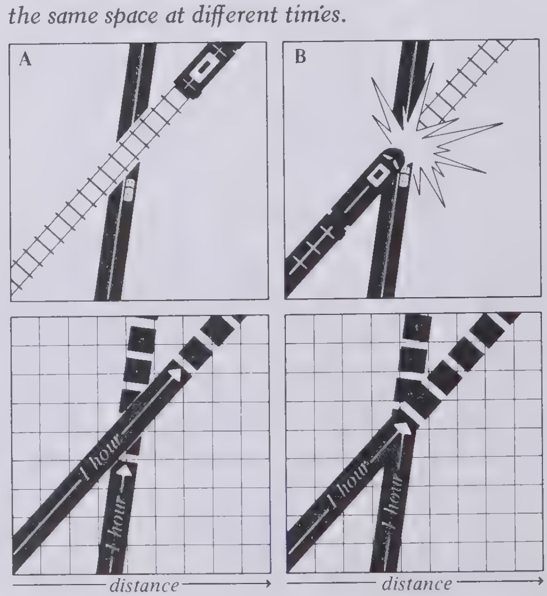
You may find that students, like other people, are so conditioned by the world they live in that they are unwilling to explore new concepts such as relativity. You might ask several thought-provoking questions for students to explore. Try at this time to avoid questions with one correct answer. Ask, for example: How does relativity seem to give man opportunity for distant space travel? Can man travel into the past? How could man travel into the future?

22–10
The relativity of time
22–11
Time: the fourth dimension

An excellent reference for this section, and Sections 22–8 and 22–9 as well, is *Time* from the Time-Life Science series. It contains a number of novel approaches to this topic.

To anyone who has ever been kept waiting for an appointment or arrived at a party too early, the relativity of time should be easy to understand. Guide Figure 22–4 shows that if an automobile crosses a railroad track when the train is

Guide Figure 22–4
One way to show that objects may occupy the same space at different times.



not there, everything is fine. Both the train and the auto can occupy the same space if they do so at different times. If, however, the lines in the drawing cross, it means the auto and train have reached the track at the same time. The result is a collision.

In terms of relativity, the crossing of those lines is called an event. The difference between two events is the combination not only of the distance in space but also of the distance in time. This concept can be emphasized by having students measure the length of the room. Ask them to record the measurement on a piece of paper. You can then state that the room has changed. After some discussion students should conclude that only the time has changed. Time must be the dimension of the room that changed.

22–12
The origin of the universe

In this section you might want to emphasize that science is not like an athletic contest. A scientist doesn't take sides, trying to see his view accepted by all. Instead, a good scientist tries to find some evidence that will break down even his favorite theory.

Point out that no number of positive supporting facts will *prove* a theory. One negative fact, however, will disprove it. For an example of this, refer back to Ptolemy's theory of the solar system. Students should recall how scientists calculated complicated movements for almost all the bodies in the sky to explain their apparent orbits. By establishing only one point, that the earth moved around the sun, it was possible to disprove Ptolemy's entire theory.

Answers to thought and discussion

1. According to the theory of relativity, can an object have an absolute mass and length? **Answer** An object with an absolute mass and length would have to be moving at the speed of light. According to the theory, this seems impossible. No amount of force would be able to move an object that had an absolute mass and length.
2. Can anything really be said to be at rest, or "standing still?" **Answer** As far as astronomers have looked in the universe, every object they have seen seems to be moving.
3. What does moving at 70 miles per hour really mean? Does one always have to say "with respect to what?" **Answer** Moving at 70 miles per hour means that an object travelling at that speed would move a distance of 70 miles from its starting point in one hour. Calculation of an object's speed from a moving object would tell us only the *apparent* speed of the object. The starting point must be a stationary object if the object's real speed is to be calculated. One must always say "with respect to what" when giving the speed of an object. For example, a person at a stationary point on the ground might measure the speed of a car at 60 miles per hour. Another person, aboard a train moving at 50 miles per hour in the same direction as the car, would measure the speed of the same car at 10 miles per hour.

Discussion of unsolved problems

In the opening activity of this course students were asked to think about their environment, about how they fit into the world. Since then they have discussed and investigated many different views of the world, from the sub-microscopic structure of atoms to the seemingly boundless universe. Have the students changed their ideas? As a closing activity you might ask students to write down how they would describe their home to a visitor from outer space. Does this address differ from the address they gave at the beginning of the course? If so, how?

Answers to questions and problems

A

1. What is the only galaxy we can see "from the outside" using our eyes alone? **Answer** The only galaxy we can see using our eyes alone is the Andromeda Galaxy. It is the nearest galaxy to our own.
2. What things are there in a galaxy besides stars? **Answer** Besides stars a galaxy contains planets, moons, comets, meteors, dust and clouds.
3. Suppose two Cepheid variables have the same apparent brightness, but one has twice as long

a period of variation as the other. Which one is farther away from us? **Answer** The Cepheid variable with the longer period is farther away from us than the Cepheid variable with a shorter period.

4. How many kilometers does the sun travel in one "cosmic year"? **Answer** Distance equals the rate multiplied by the time. It's easier to figure if you keep track of the units: (the rate) 250 kilometers/second × (the time) 60 seconds/minute × 60 minutes/hour × 24 hours/day × 365 days/year × 200,000,000 years/cosmic year. All that works out to a distance of $15{,}768 \times 10^{14}$ kilometers.
5. Is our galaxy a spiral or an elliptical galaxy? **Answer** Our galaxy is a large spiral galaxy.
6. What is the importance of Cepheid variables to the astronomer? **Answer** Cepheid variables are very important because astronomers can measure the distance to one of these stars. This is one way to determine the distance to the galaxy containing the Cepheid variable.

B

1. Why are the constellations of the summer sky different from those in the winter? **Answer** The summer sky and the winter sky are different because the earth orbits the sun. Viewing the sky from opposite ends of this orbit give people on earth a chance to see different sections of the universe.
2. If two stars appear to have exactly the same brightness yet one is actually 100 times brighter than the other, how much farther away is it? **Answer** If one star were actually 20 times brighter it would be about twice as far away. In this case, the brighter star must be about five times farther away.
3. The farther out in space a celestial object is, the farther back in time it appears to us. Is this a way in which time can be considered a fourth dimension? **Answer** Time is an important part of the position of any body. In this case, time is a fourth dimension because the farther away a celestial body, the more time its light takes to reach us.
4. Discuss man's possible future on earth. How much time does the sun "give" the human race? What sort of things could cut this future short? What control does man have over his future? **Answer** The sun gives man over five billion more years on earth. Beyond this theoretical limit, the answer to the question is open-ended. Natural or cosmic disasters could cut short man's future on earth. Or man himself could cut short his future. Man must learn to make wise use of his resources and his emotions. Students may answer, for instance, that the future of fossil fuels is very short compared to the time span of life offered by the sun.
5. Call one round trip of the sun around the galaxy a "cosmic year." What kind of life was there on the earth five cosmic years ago? ten cosmic years ago? **Answer** If there was any life on earth five cosmic years ago, it must have consisted of single-celled organisms. There probably was no life on earth ten cosmic years ago.

C

1. An astronomer observes a galaxy to have a "red shift" of 0.10. What is the speed of the galaxy? Is it moving toward or away from us? The formula is: speed of object = wavelength shift × speed of light. **Answer** The galaxy is moving away from us at a speed of 30,000 kilometers per second.
2. Suppose we were looking at the earth's path from a place some distance from the solar system. What would the earth's orbit look like to us then? Diagram the path of the earth as seen from outer space.(Keep in mind that while the earth travels 30 kilometers in one second in its journey around the sun, it travels with the sun some 250 kilometers in that same second of time.) **Answer** An approximate diagram is shown in Guide Figure 22–5.

Guide Figure 22–5
Path of the earth seen from beyond the solar system.

3. Light travels with the speed of light, of course. Does this mean that a beam of light takes no time (according to its own wristwatch), to go from the Milky Way to the Andromeda galaxy? **Answer** Yes. According to the theory of relativity, at the speed of light time ceases to pass.
4. The origin of everything we see about us on earth and in the universe was probably the element hydrogen. Where do you think the hydrogen came from? **Answer** Hydrogen may have been formed when subatomic particles collided in space, or hydrogen may have formed directly from energy through some unknown process.
5. Think of the sun's orbit around the galaxy. The sun moves 250 kilometers per second. Even so, its orbit is so large that it takes over 200 million years to make one complete circuit. Try to prove the following statement. The center-line of a straight superhighway is no straighter over a mile's length than is the sun's orbit around the galaxy in a year's time. (Hint: assume that the center line of the highway does not vary more than a few inches in the course of a mile.) **Answer** The circle formed by the orbit of the sun is so large that the arc traced in one year is almost a straight line. In fact, 1/200 million of the circumference of any circle is almost a straight line.
6. In a science fiction story a message was sent from one civilization to another across the far reaches of our galaxy. It was described as "the long-since-dead talking to the not-yet-born." What did that statement mean? **Answer** By the time the message arrived, it was received by people who were not even born when the message was sent. The people who sent the message had died long before the message reached its destination.

Supplementary Materials

Reference books

Bergamini, David and the editors of *Life*. *The Universe*. Time-Life, Inc., New York, 1969.

Branley, Franklyn M. *The Milky Way: Galaxy Number One*. Thomas Crowell, New York, 1969.

Claiborne, Robert and Goudsmit, Samuel. *Time*. Time-Life, Inc., New York, 1966.

Dexter, William. *Field Guide to Astronomy Without a Telescope*. Houghton Mifflin Company, Boston, 1971. Earth Science Curriculum Project PS-9.

Films

Reflections on Time. 22 minutes, color. Encyclopaedia Britannica Educational Corp., 1969.

Cosmic Zoom. 8 minutes, color. McGraw-Hill Text-Films, 1970.

Measuring the Universe. 10 minutes, color. Bailey-Film Associates, 1969.

Space Science: Galaxies and the Universe. 14 minutes, color. Coronet Films, 1969.

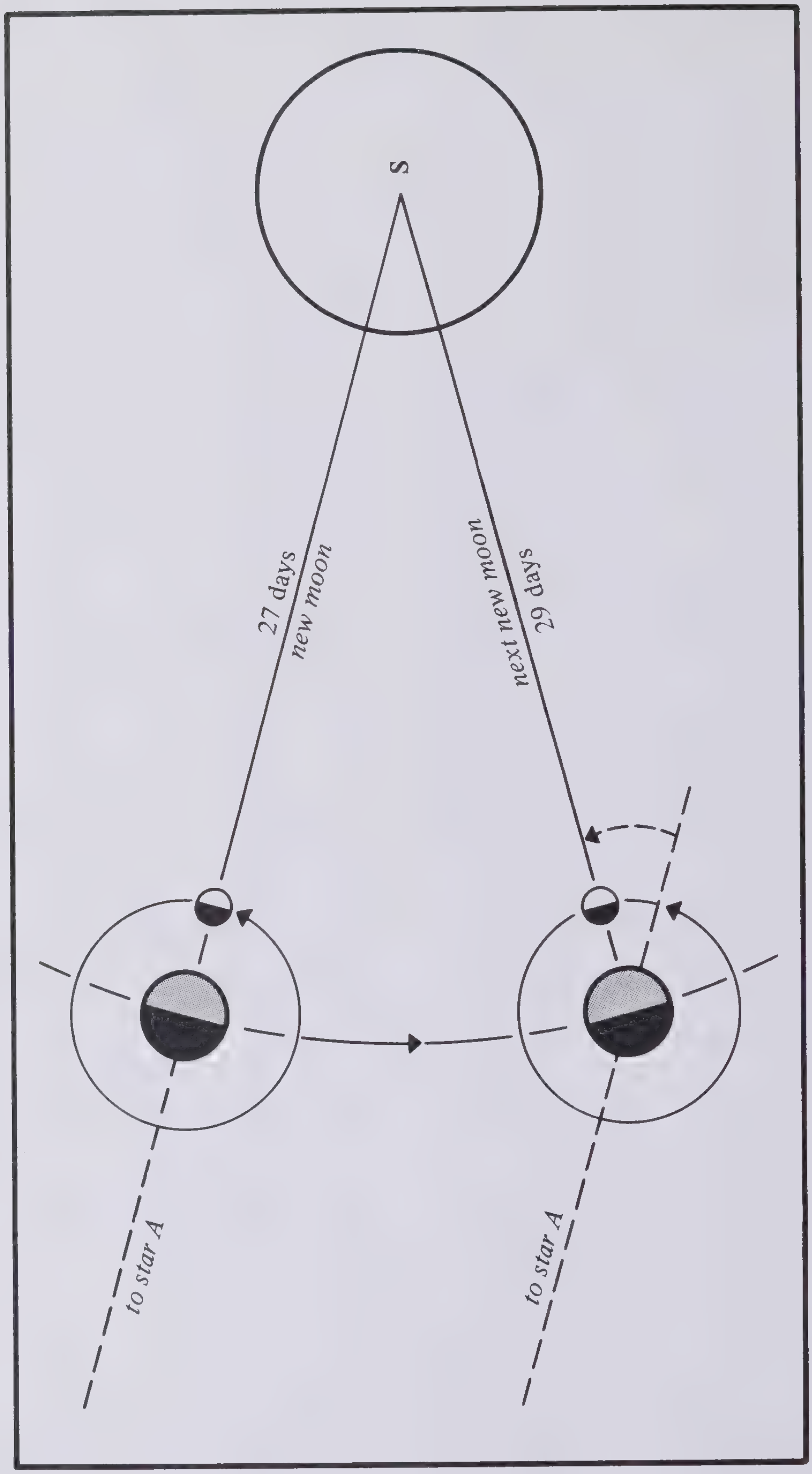
Appendix A. Transparency Masters

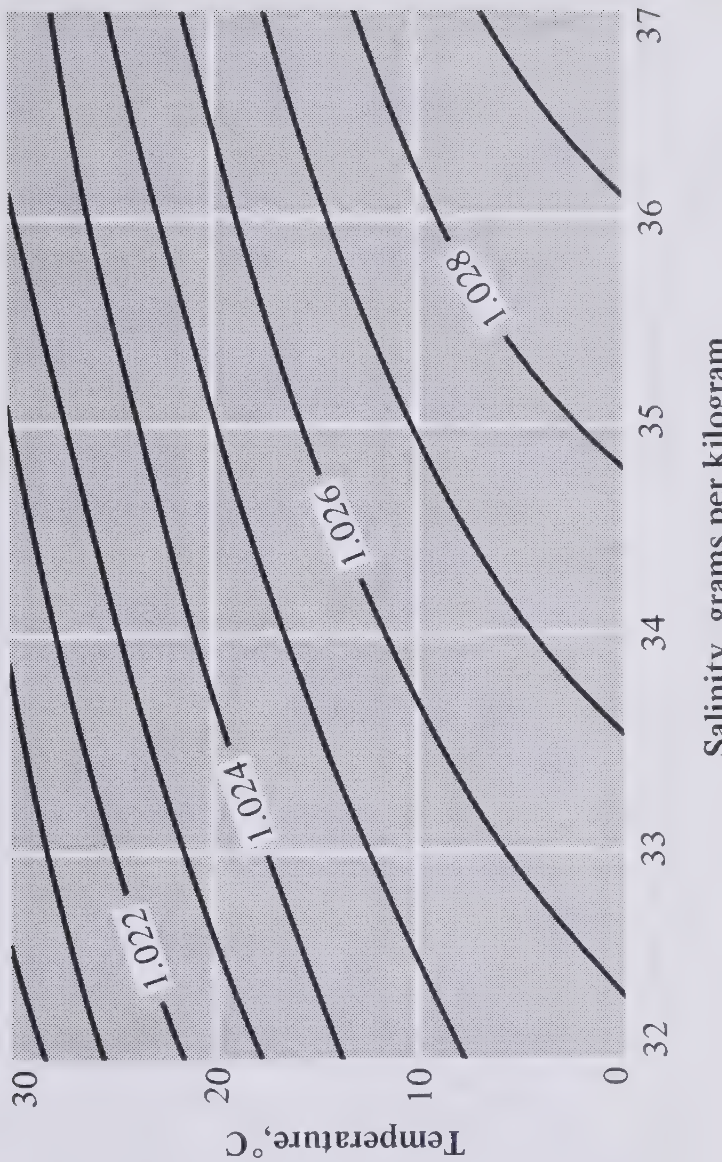
Figures in this Appendix are adapted from charts and artwork in the Text or in the Guide. You can use these full-page figures in a variety of ways. For example you might duplicate individual students worksheets for investigations or long-term observations. Overhead transparencies can be prepared from these masters to help involve students in class discussion. Transparencies also can make it simpler for you to explain a point where students have trouble. You may find many other ways to expand the use of these figures, perhaps by devising overlays or adding other illustrations to the collection.

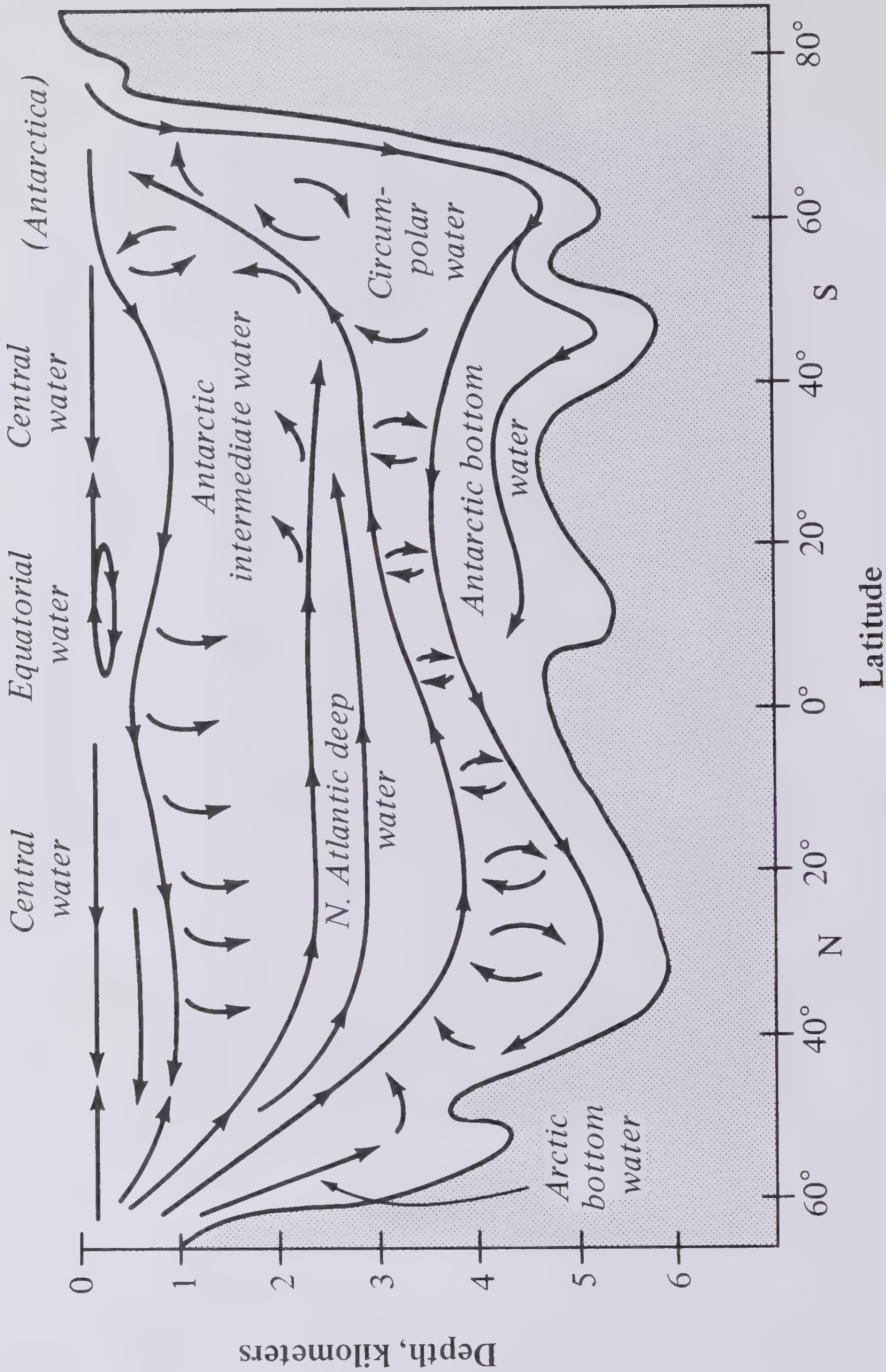
These figures appear in Appendix A:

Moon Watch Data **Name:**

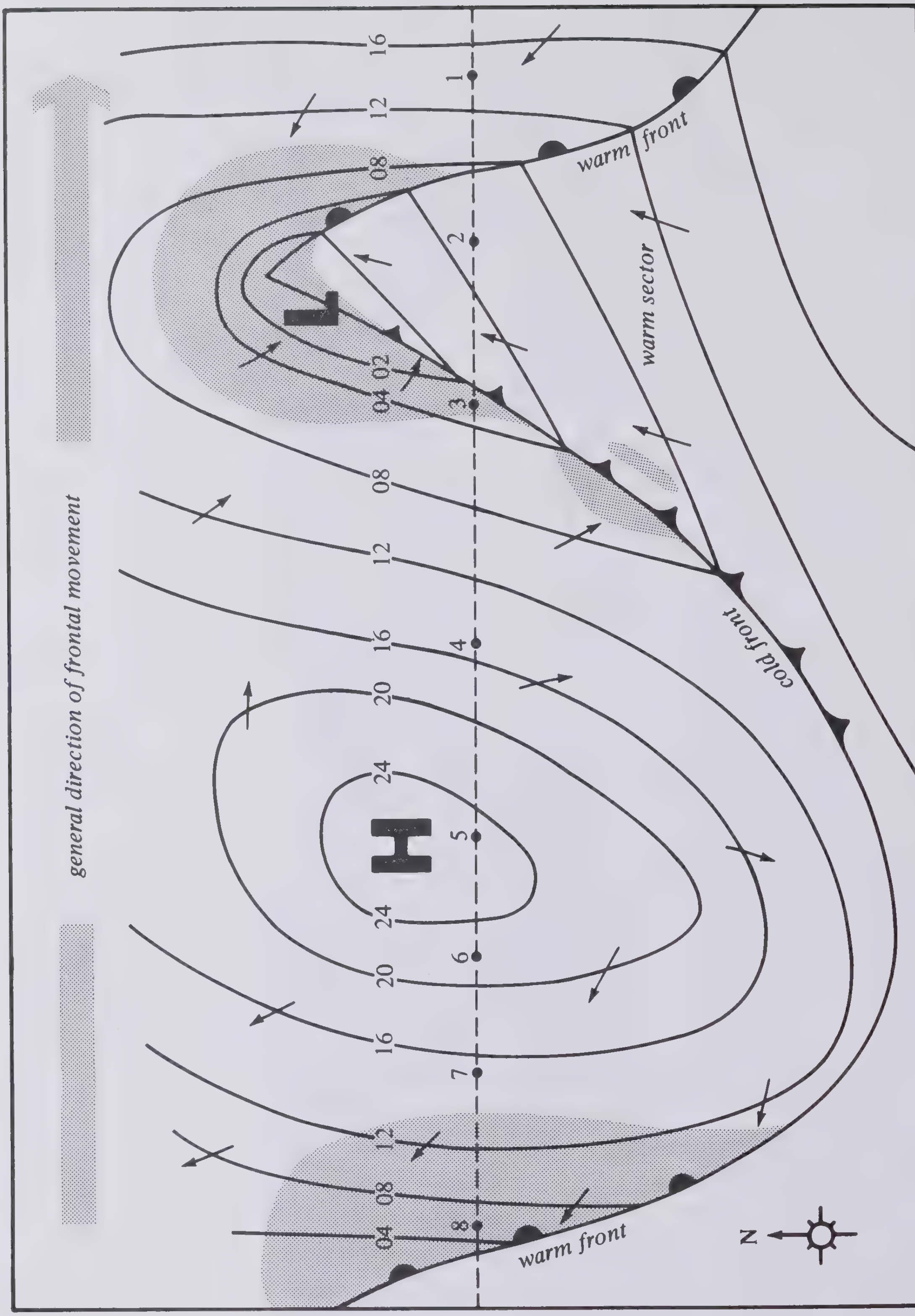
Date	*Time*	*Is the moon visible?*	*Direction (E, SE, and so on)*	*Height (horizon is 0°, overhead is 90°)*	*Moon's phase and positions of any nearby stars*

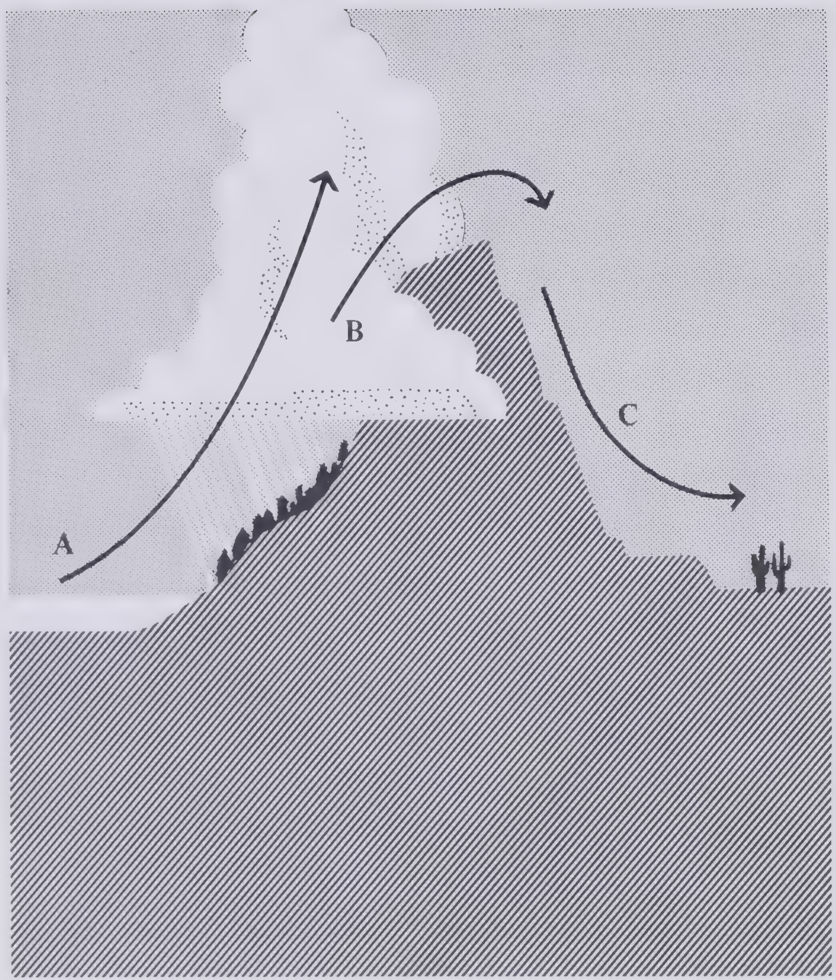

S
27 days
new moon
next new moon
29 days
to star A
to star A

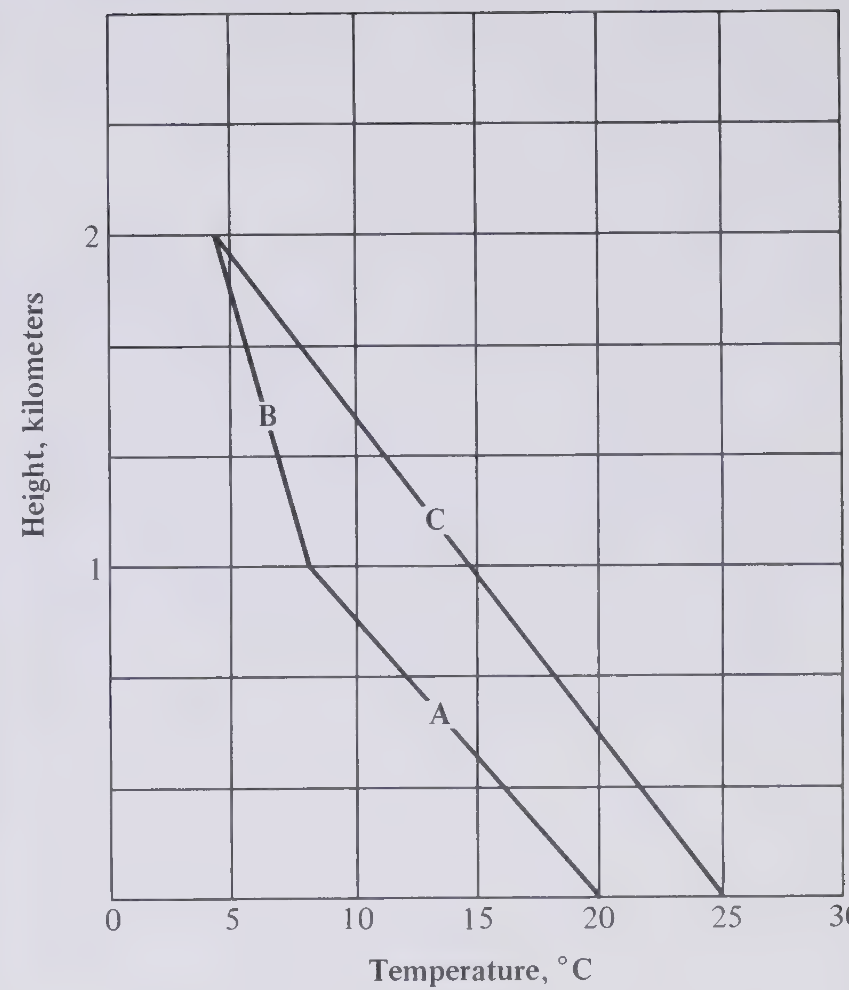

Temperature, °C
30
20
10
0
Salinity, grams per kilogram
32
33
34
35
36
37
1.022
1.024
1.026
1.028

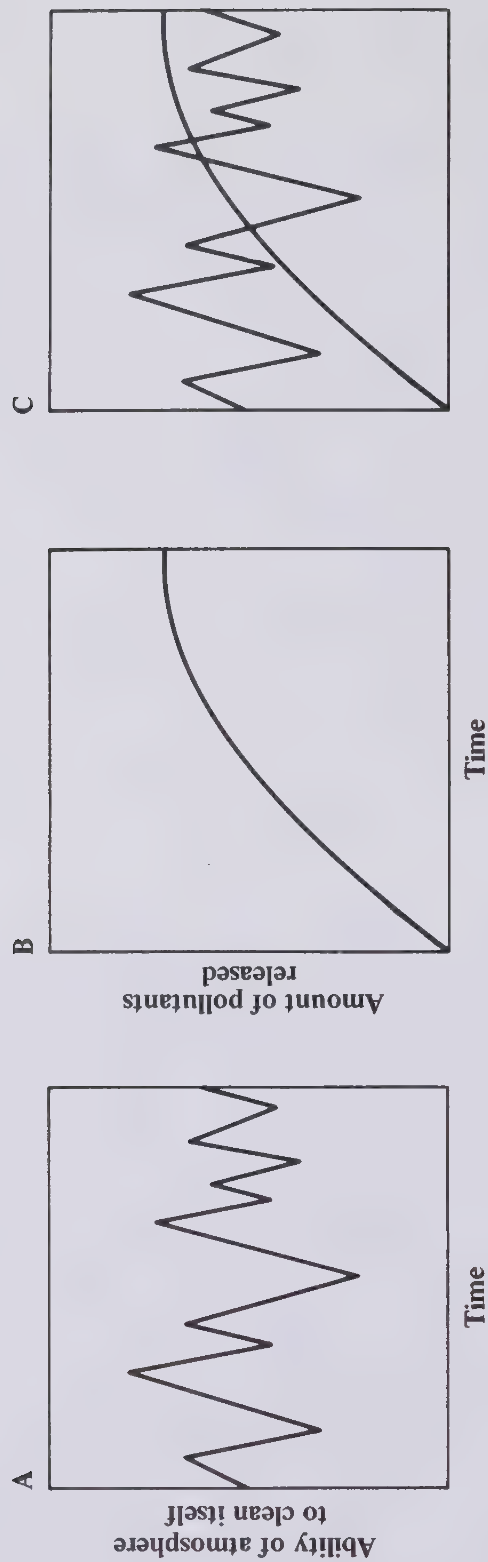


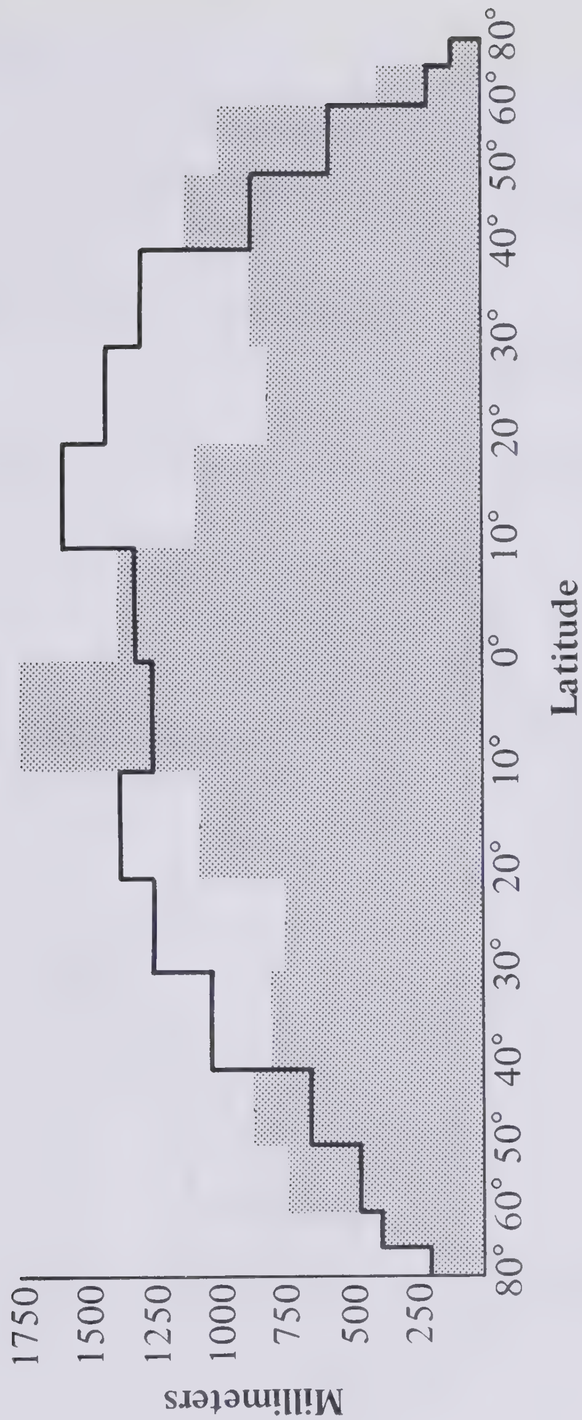
Depth, kilometers
0
1
2
3
4
5
6
Central water
Equatorial water
Central water
(Antarctica)
Antarctic intermediate water
Circum-polar water
N. Atlantic deep water
Antarctic bottom water
Arctic bottom water
60°
40°
N
20°
0°
20°
40°
S
60°
80°
Latitude

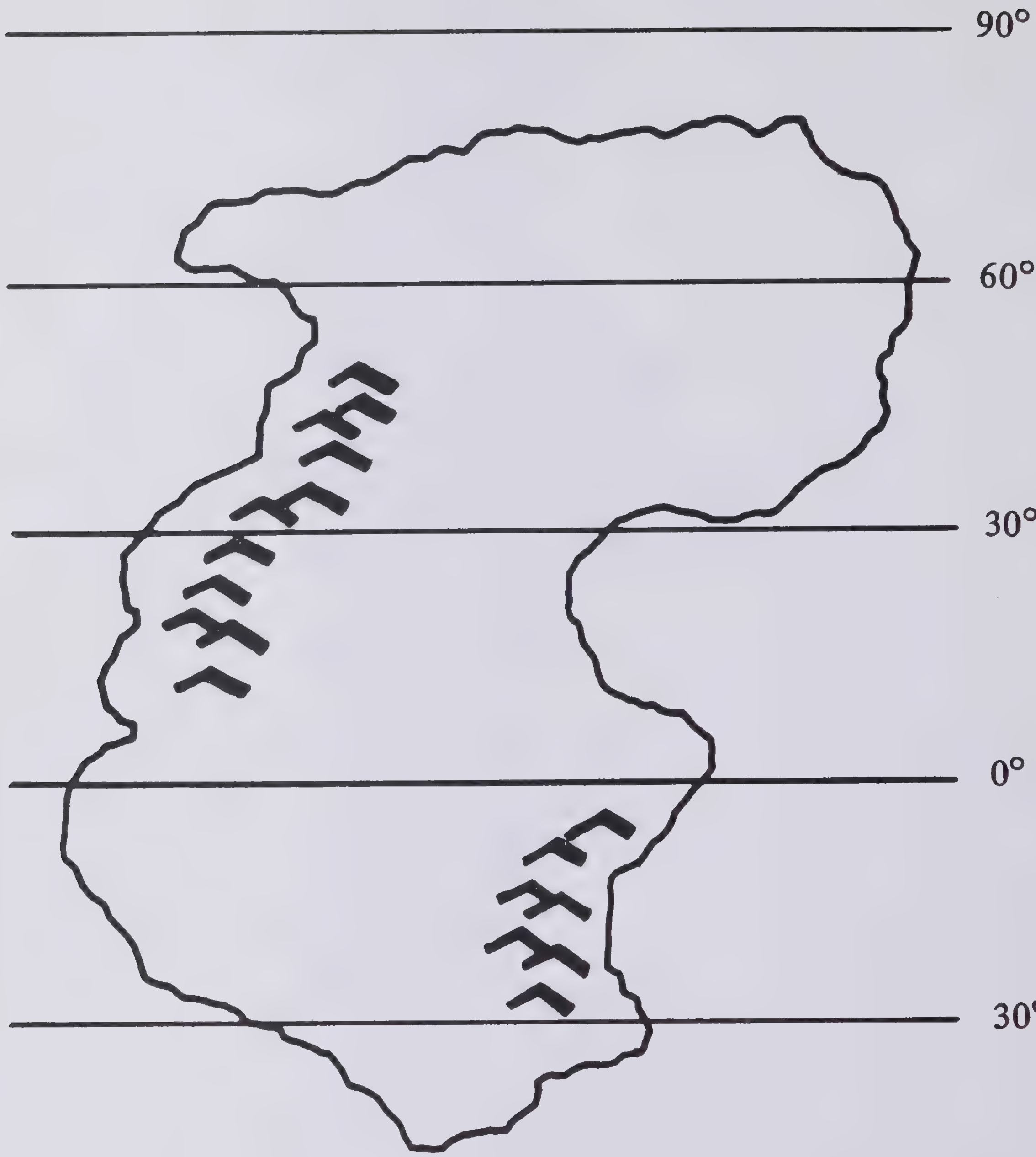

general direction of frontal movement
warm front
warm sector
cold front
warm front
L
H
N
16
12
08
04
02
20
24
1
2
3
4
5
6
7
8


A
B
C

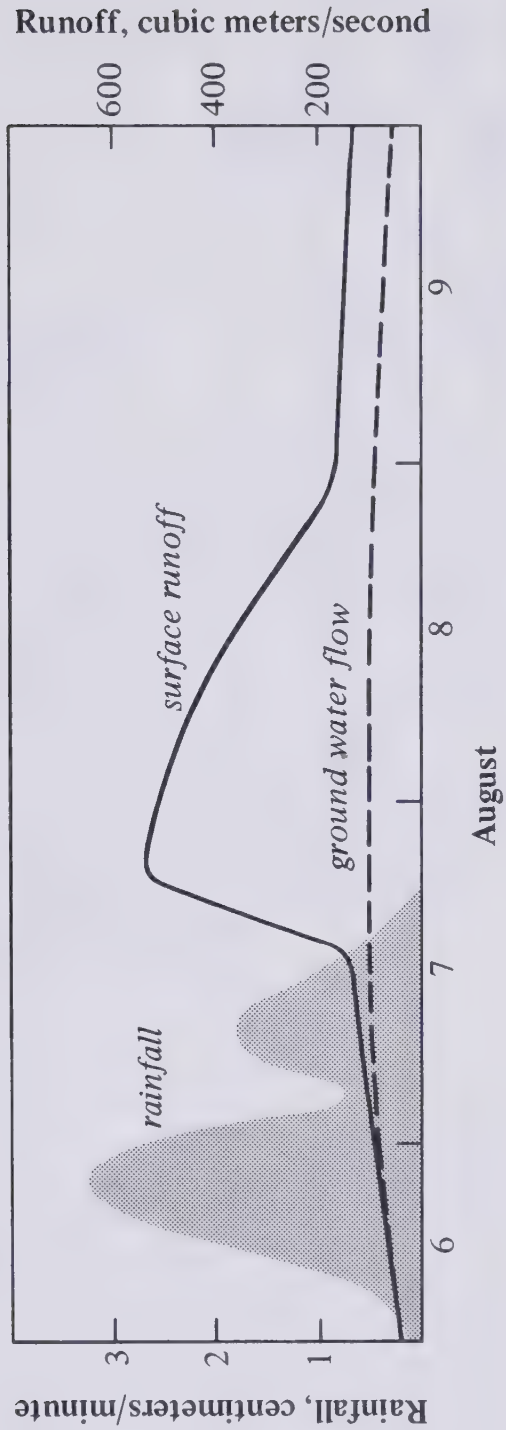

Height, kilometers
2
1
0
5
10
15
20
25
30
Temperature, °C
A
B
C

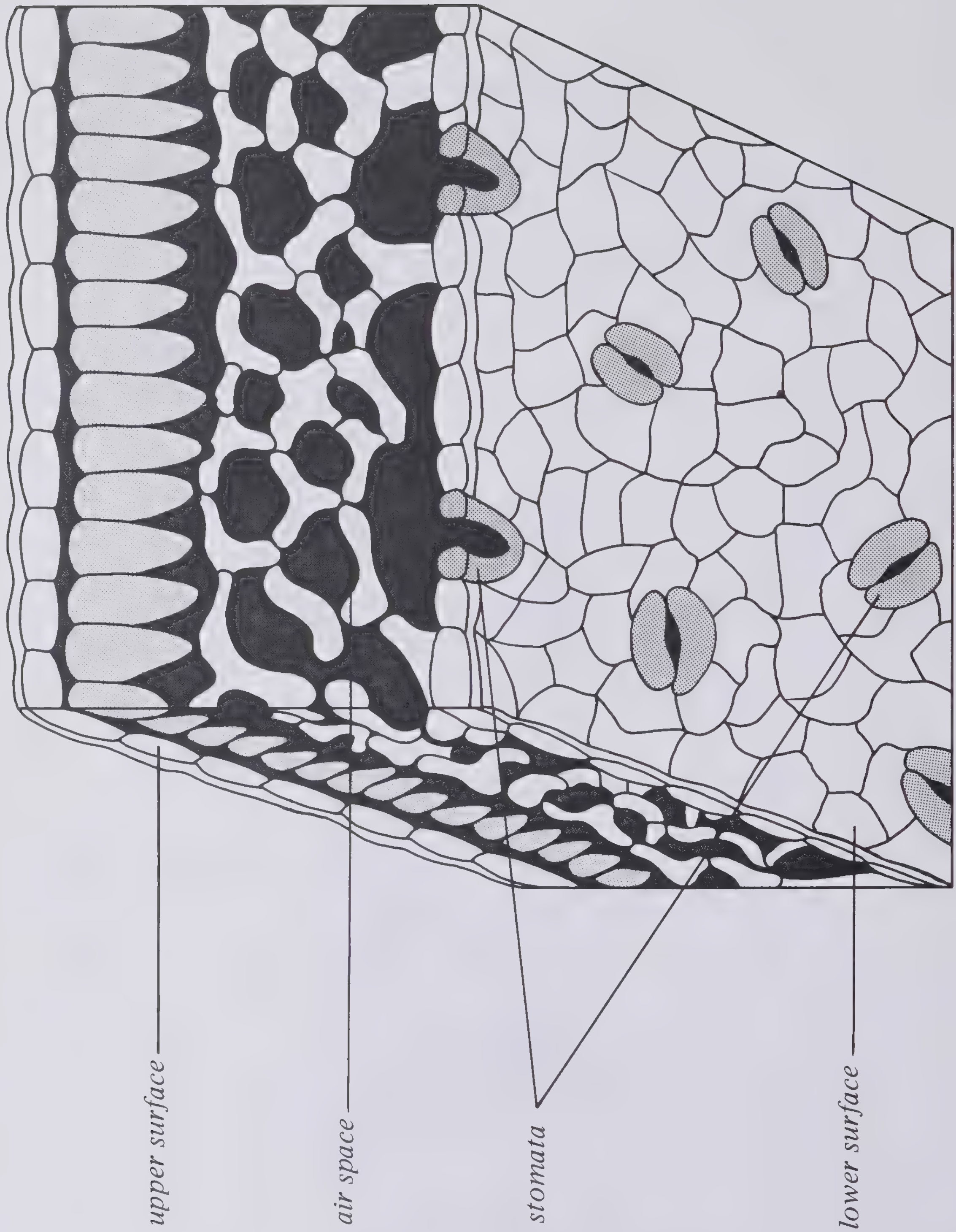

A
B
C
Ability of atmosphere to clean itself
Amount of pollutants released
Time
Time

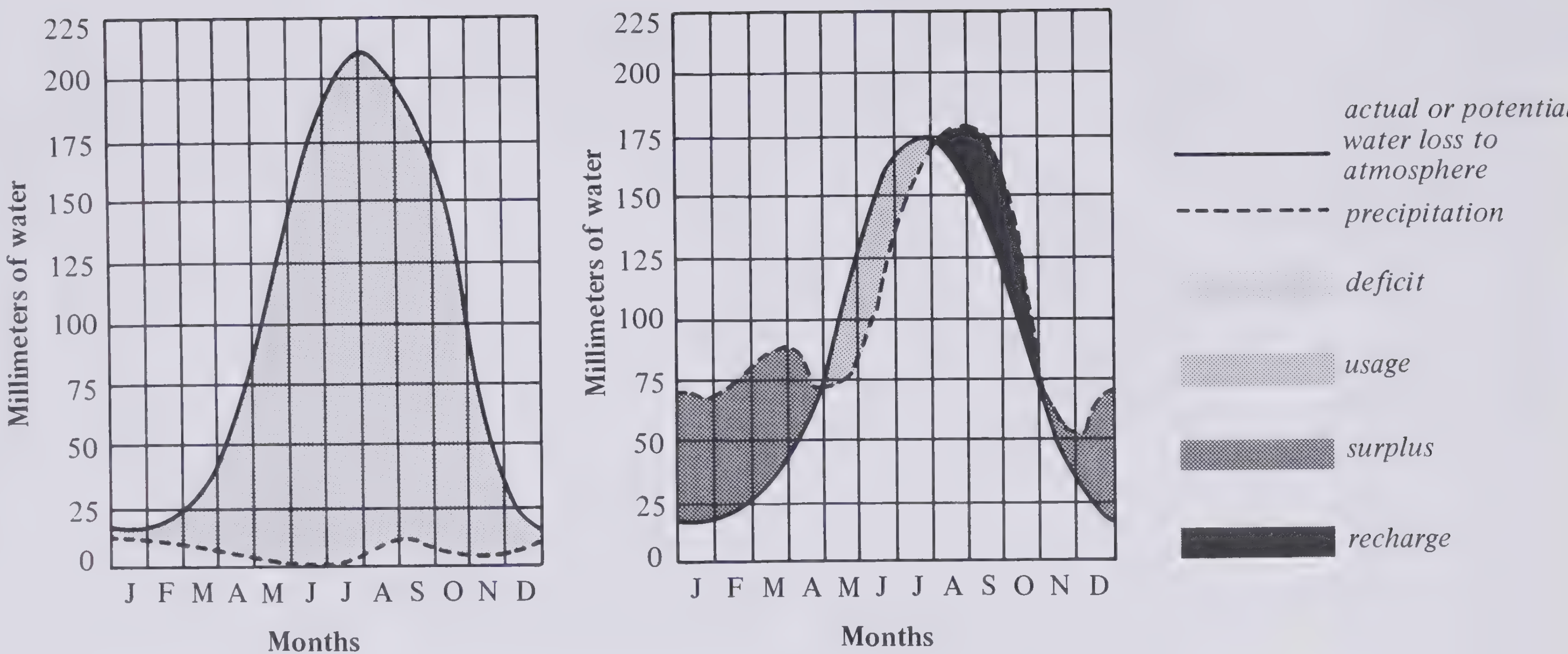

Millimeters
1750
1500
1250
1000
750
500
250
80°
60°
50°
40°
30°
20°
10°
0°
10°
20°
30°
40°
50°
60°
80°
Latitude

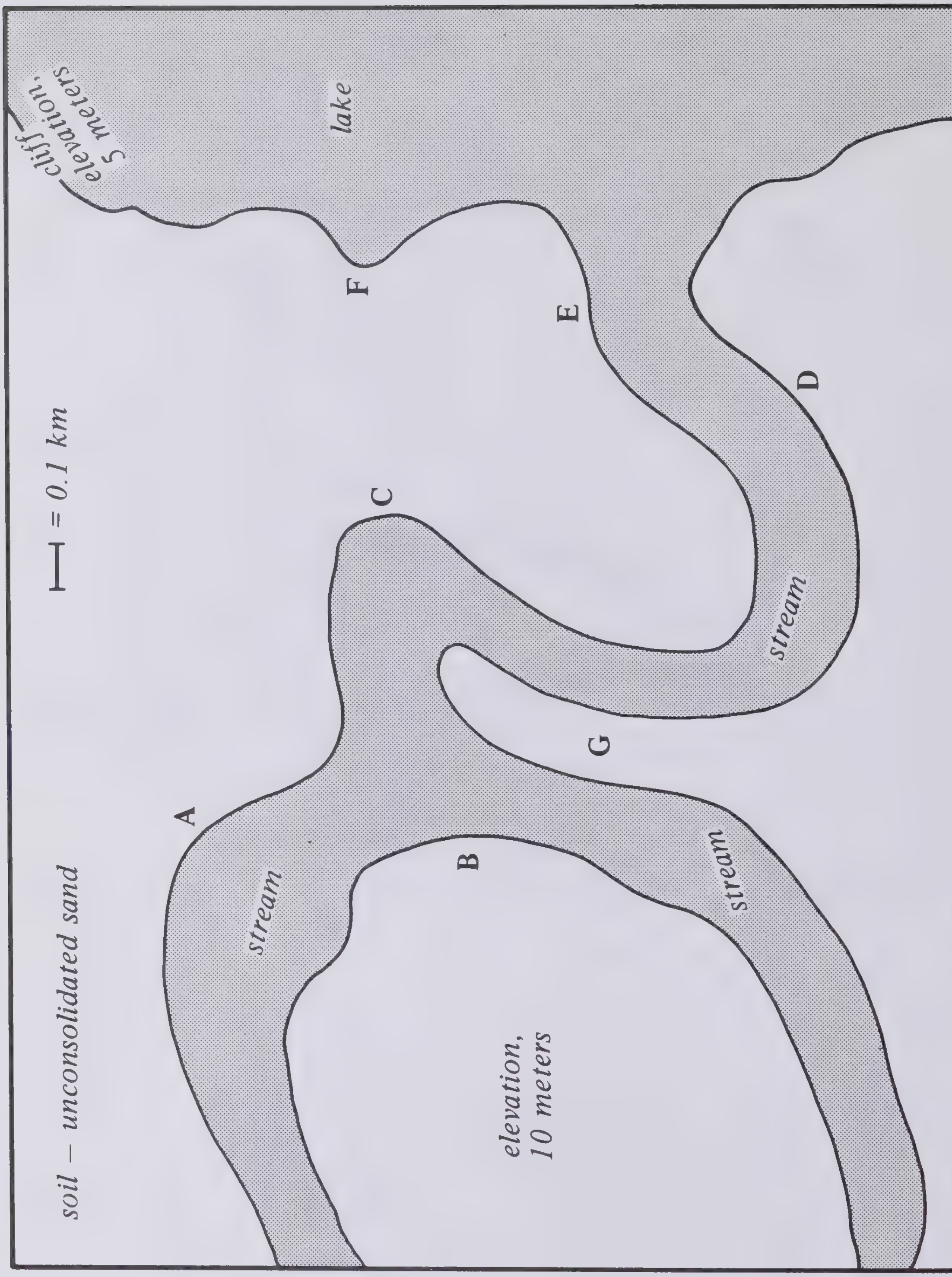


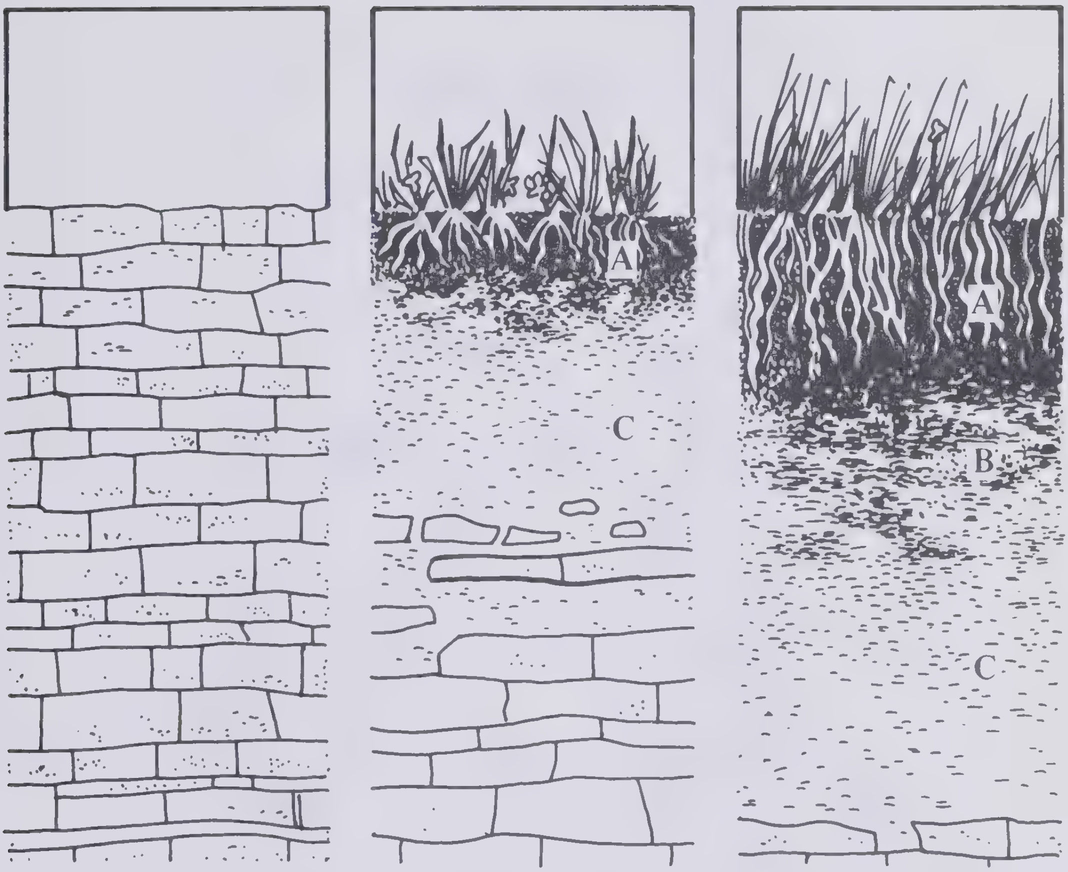
90°
60°
30°
0°
30°


Runoff, cubic meters/second
600
400
200
surface runoff
ground water flow
rainfall
9
8
7
6
August
3
2
1
Rainfall, centimeters/minute

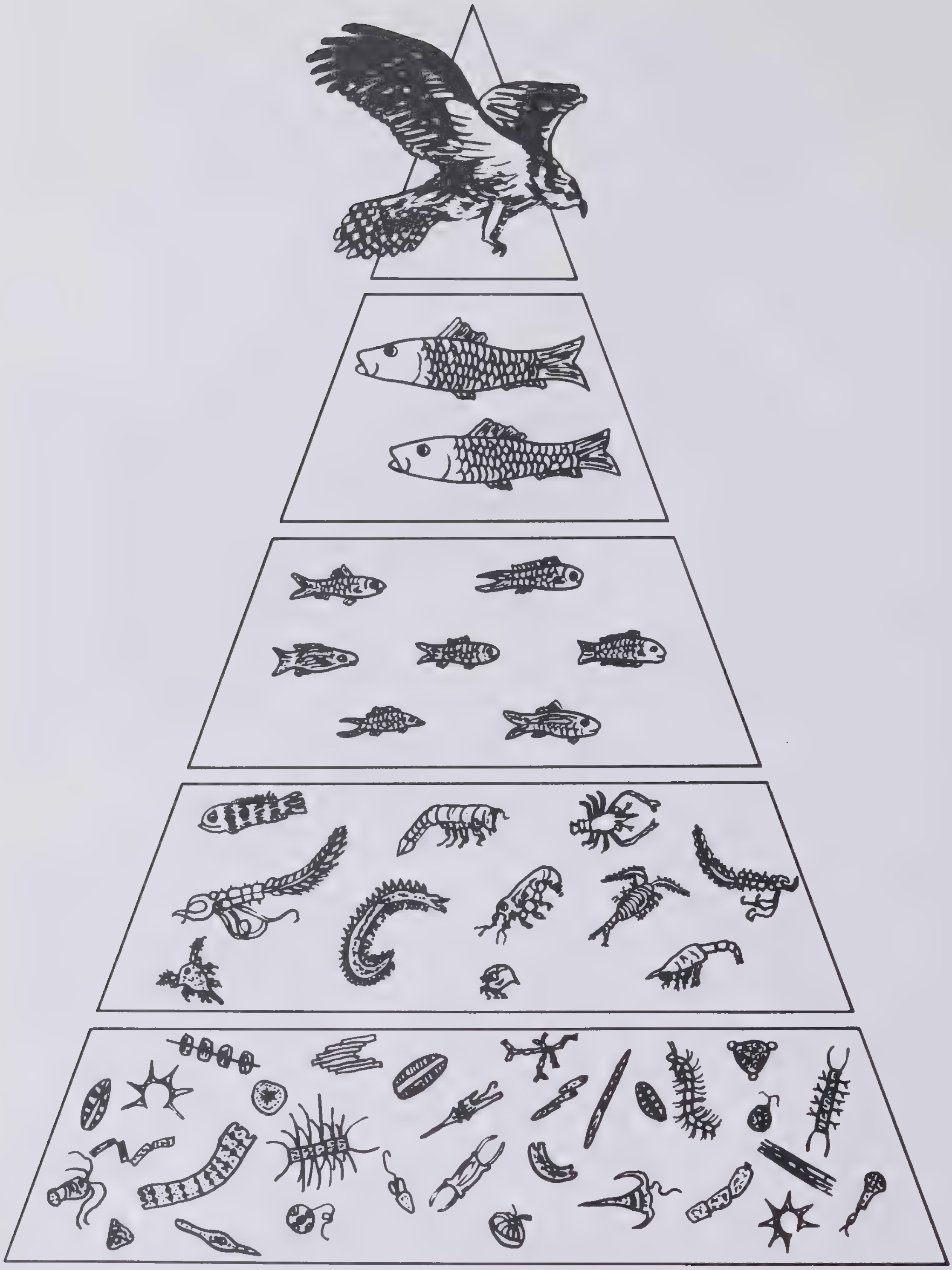

upper surface
air space
stomata
lower surface

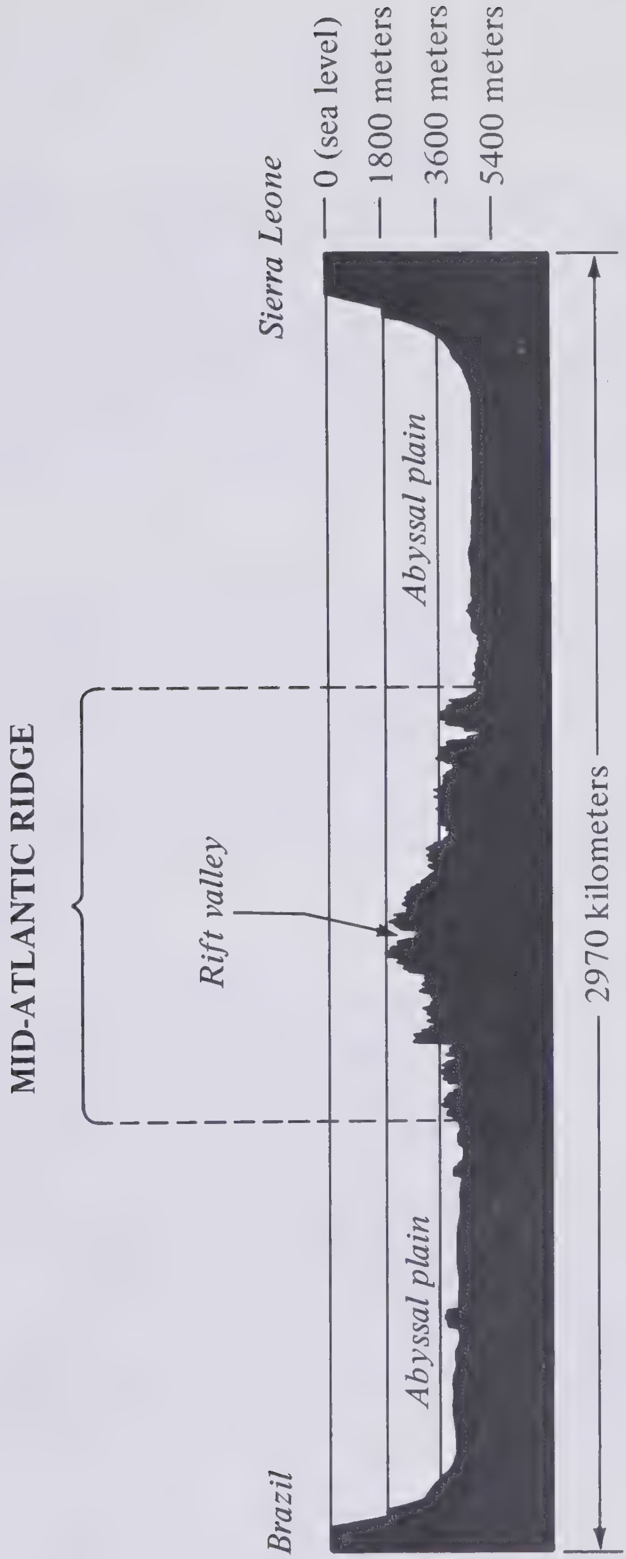

225
200
175
150
125
100
75
50
25
0
Millimeters of water
J F M A M J J A S O N D
Months
225
200
175
150
125
100
75
50
25
0
Millimeters of water
J F M A M J J A S O N D
Months
actual or potential water loss to atmosphere
precipitation
deficit
usage
surplus
recharge

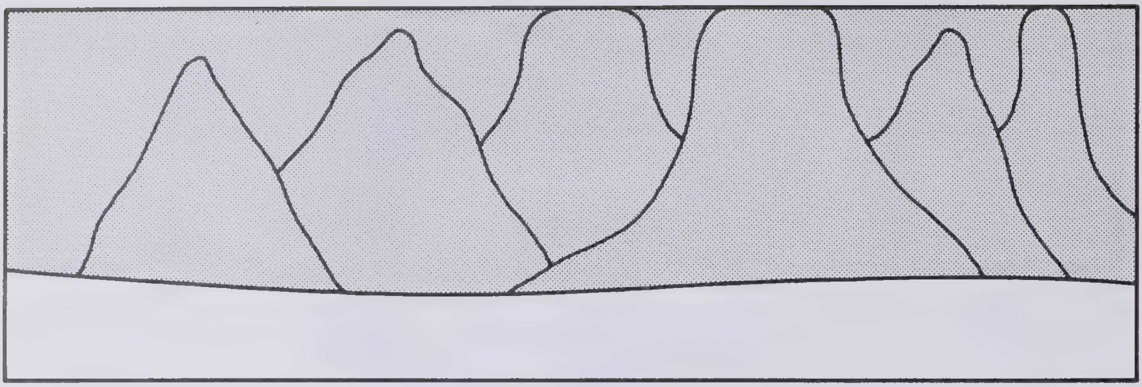

soil – unconsolidated sand
= 0.1 km
lake
cliff
elevation, 5 meters
F
E
D
C
A
B
G
stream
stream
stream
elevation, 10 meters

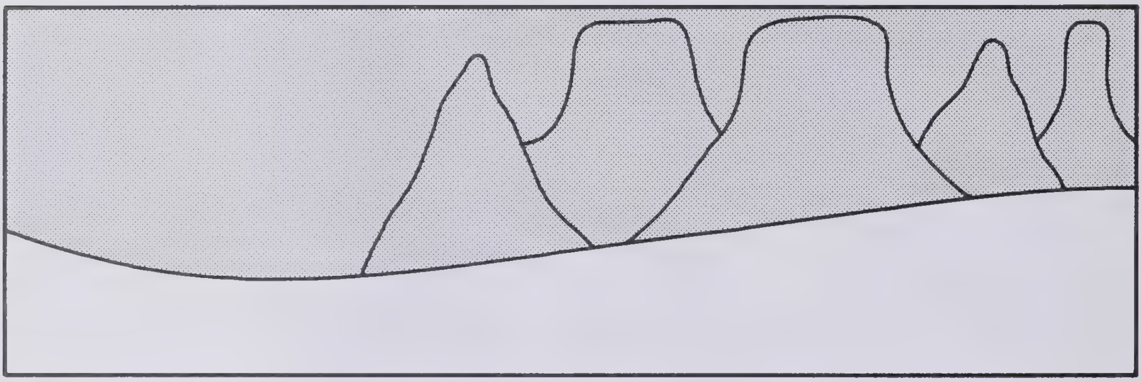


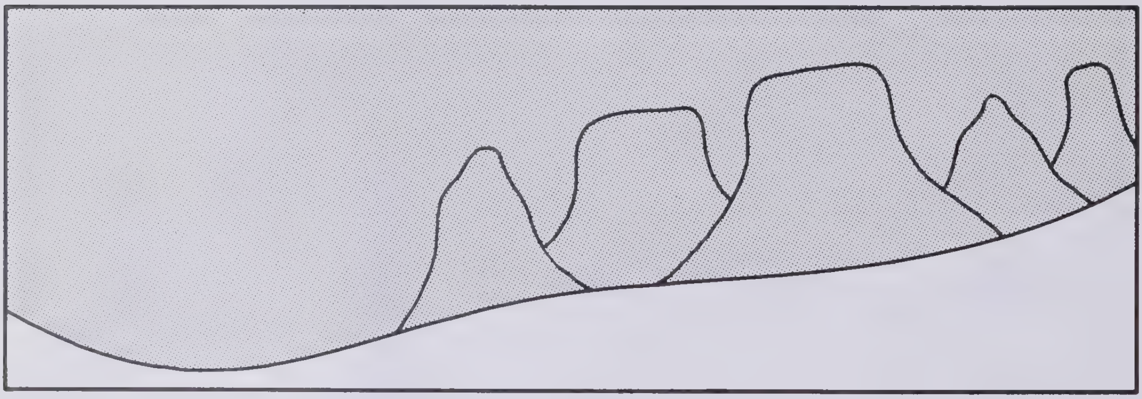
Unweathered rock　　Immature soil　　Mature soil



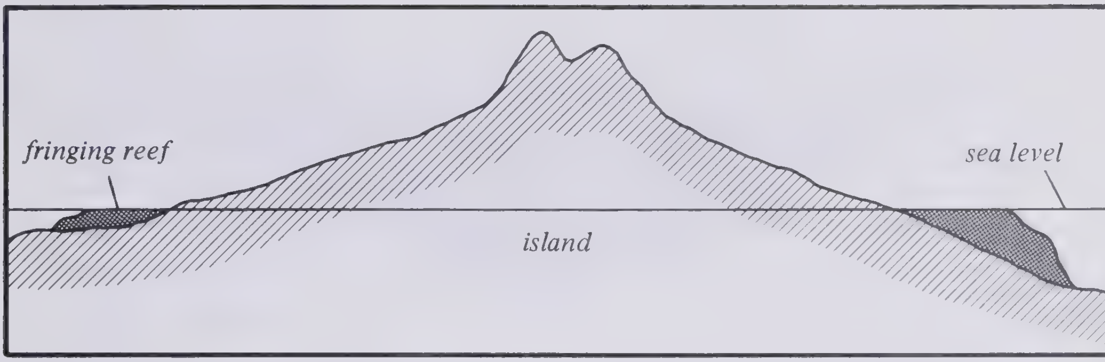

MID-ATLANTIC RIDGE
Rift valley
Sierra Leone
Brazil
Abyssal plain
Abyssal plain
0 (sea level)
1800 meters
3600 meters
5400 meters
2970 kilometers



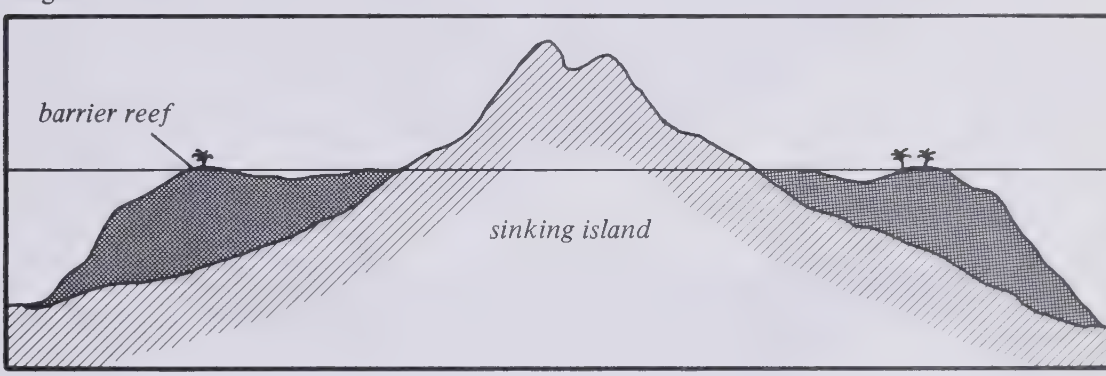




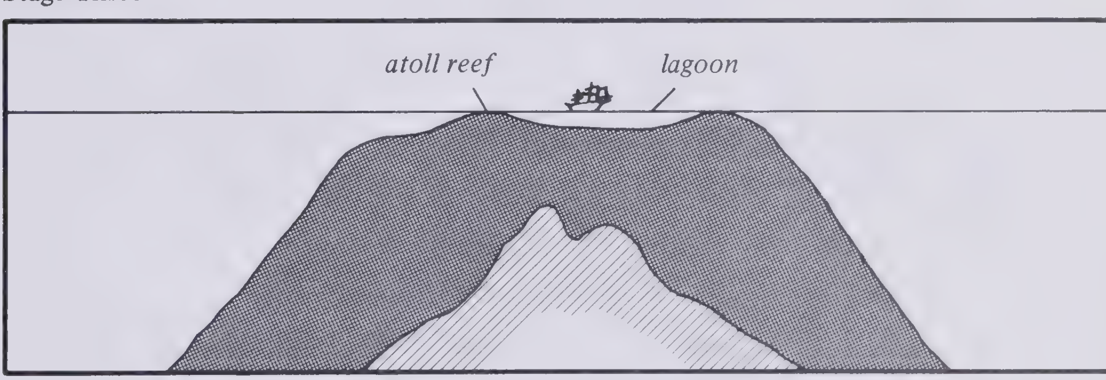
Stage One

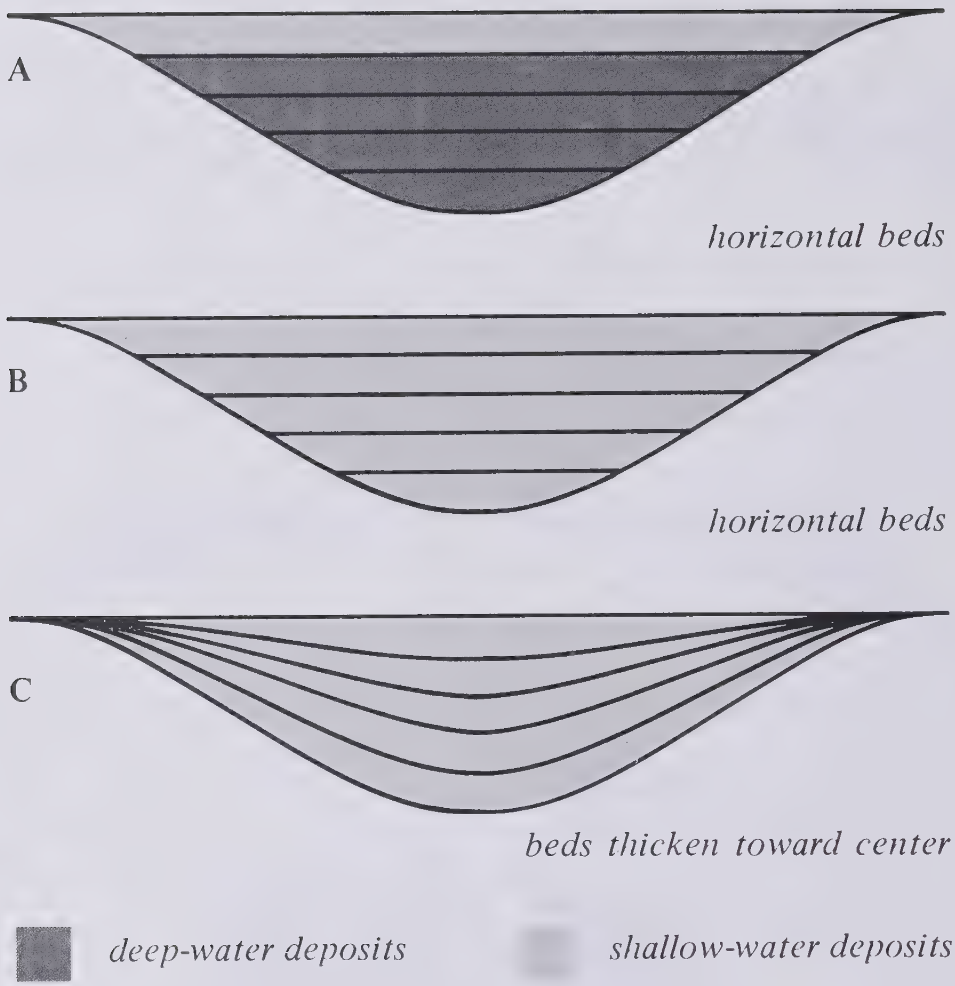


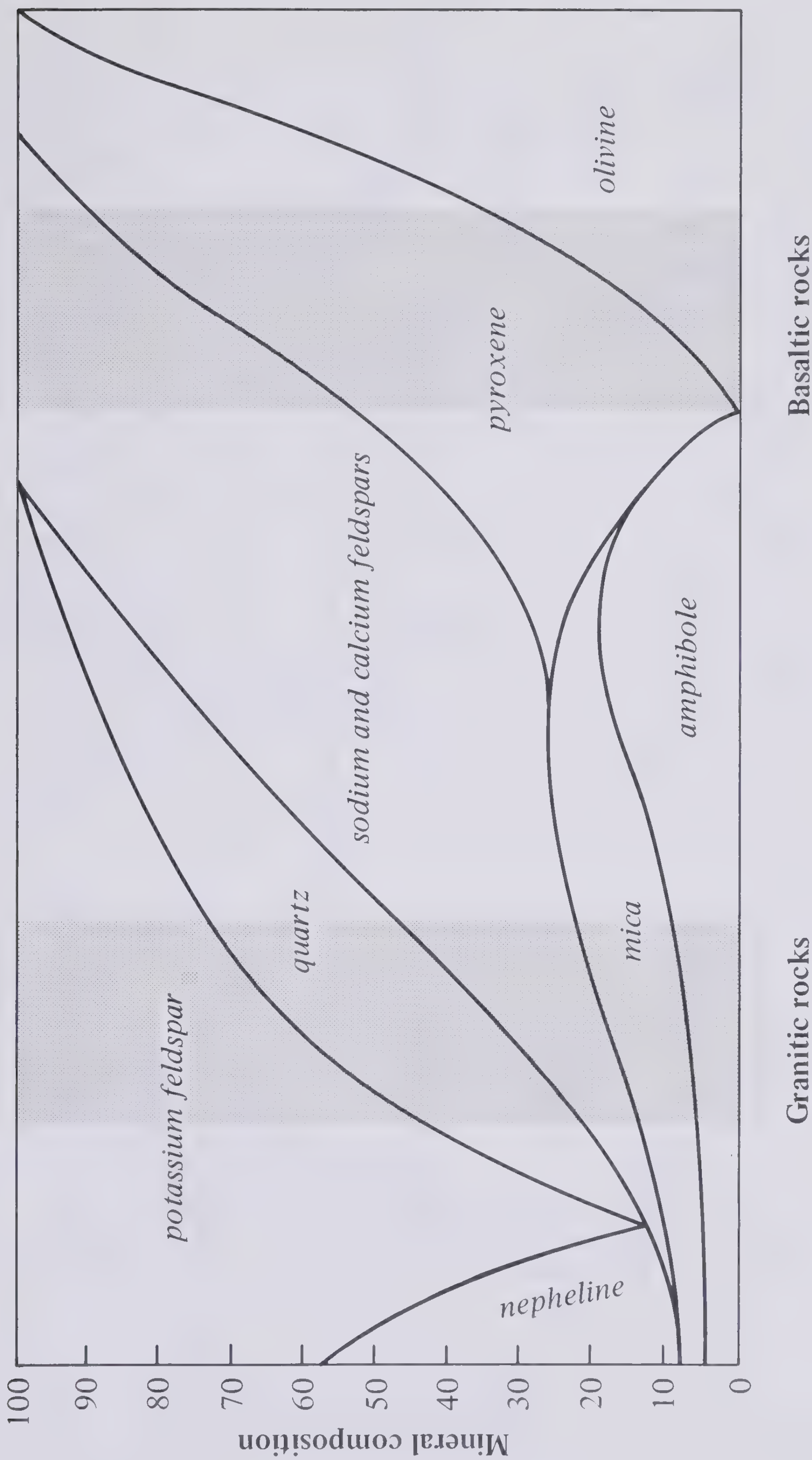
Stage Two



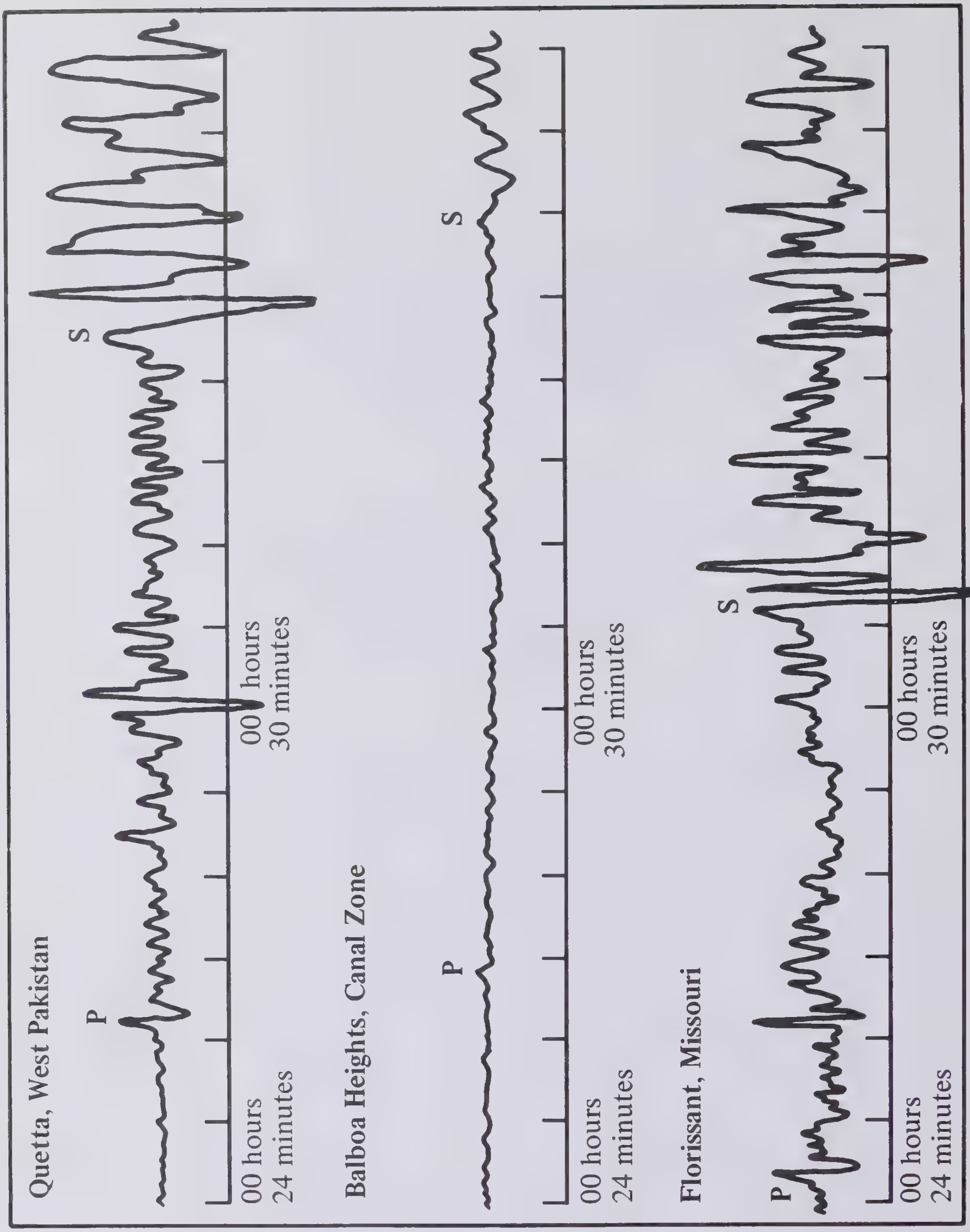
Stage Three

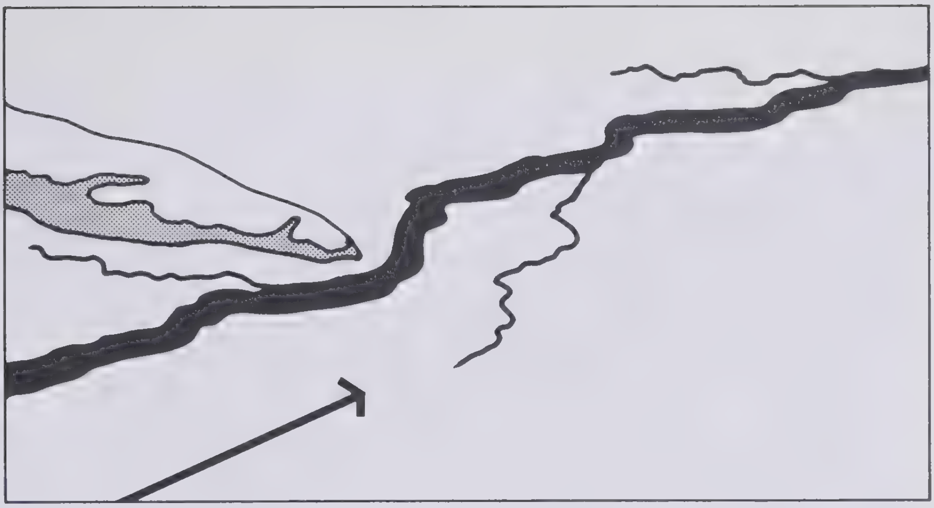


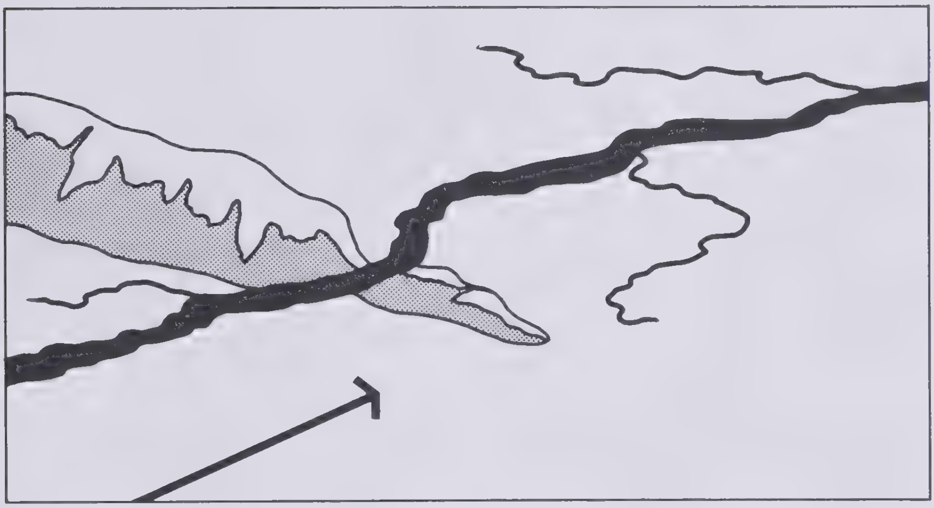

A
horizontal beds
B
horizontal beds
C
beds thicken toward center
deep-water deposits
shallow-water deposits

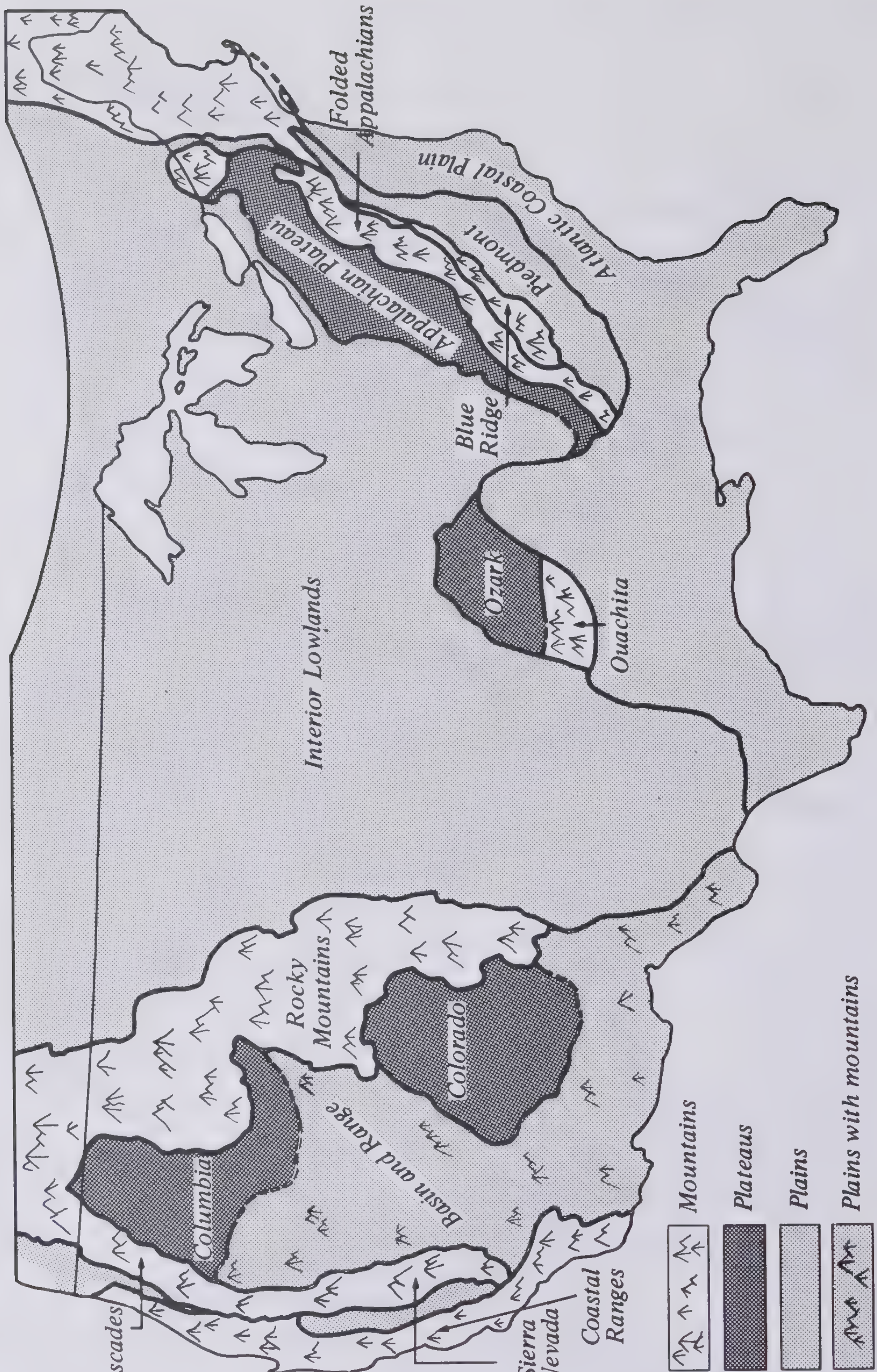


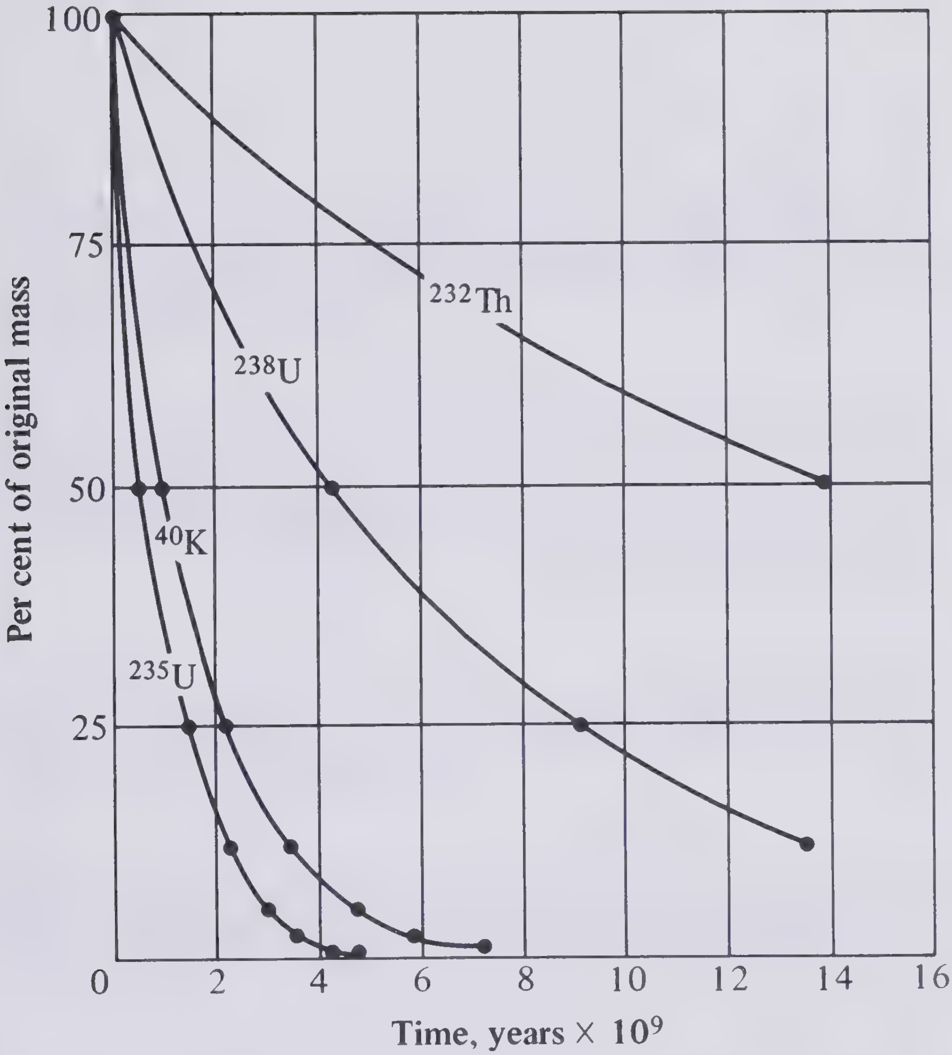
Mineral composition
100
90
80
70
60
50
40
30
20
10
0
potassium feldspar
nepheline
quartz
sodium and calcium feldspars
mica
amphibole
pyroxene
olivine
Granitic rocks
Basaltic rocks

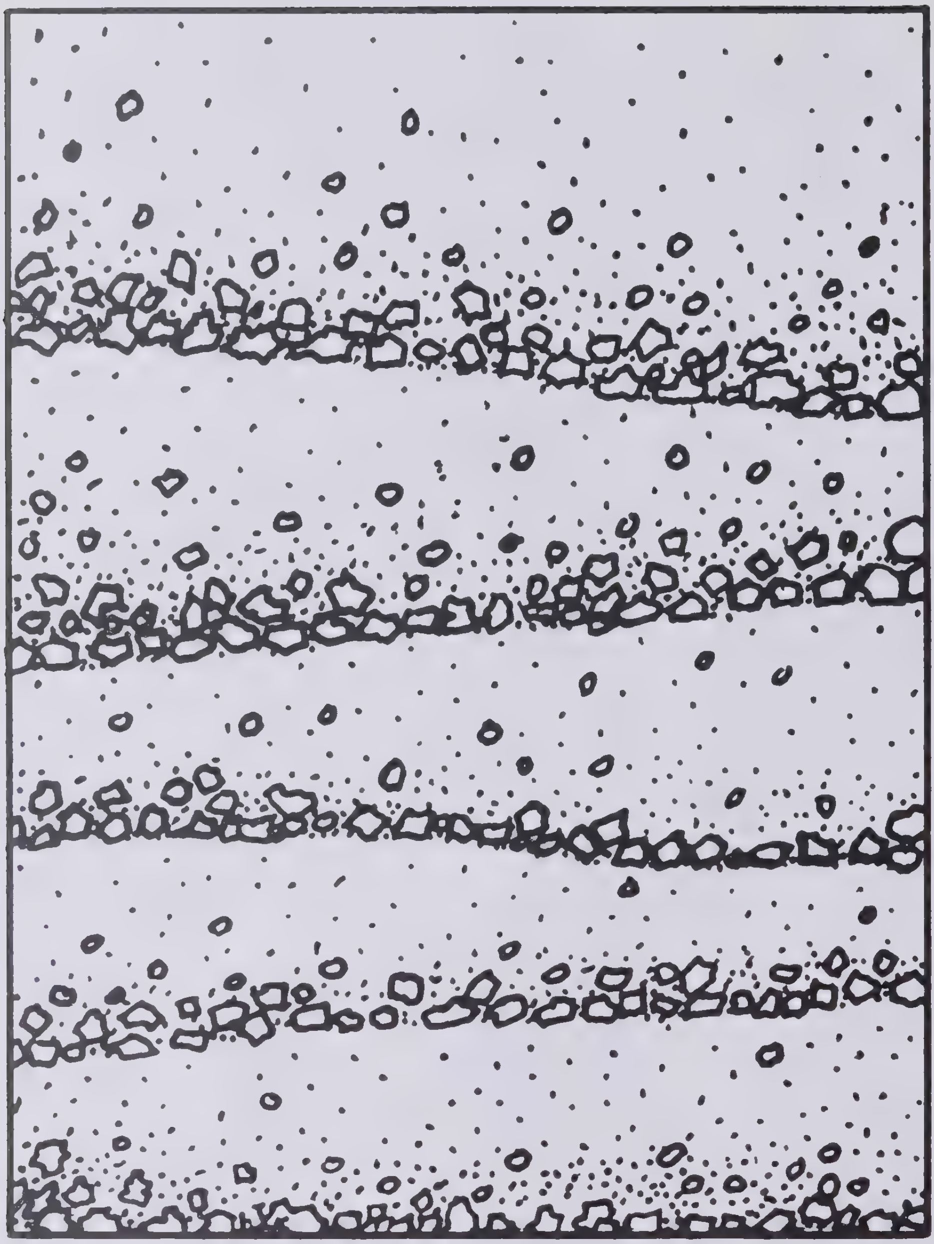

Quetta, West Pakistan
P
S
00 hours
24 minutes
00 hours
30 minutes
Balboa Heights, Canal Zone
P
S
00 hours
24 minutes
00 hours
30 minutes
Florissant, Missouri
P
S
00 hours
24 minutes
00 hours
30 minutes

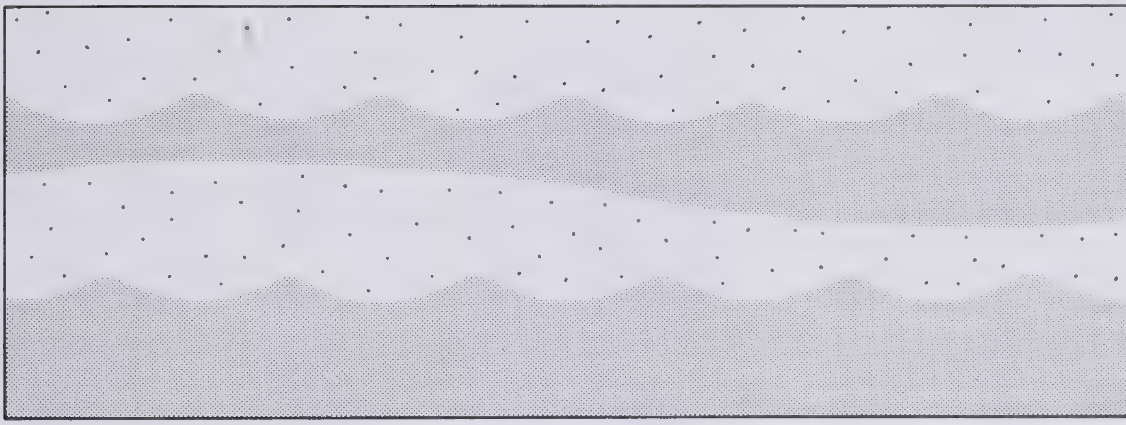


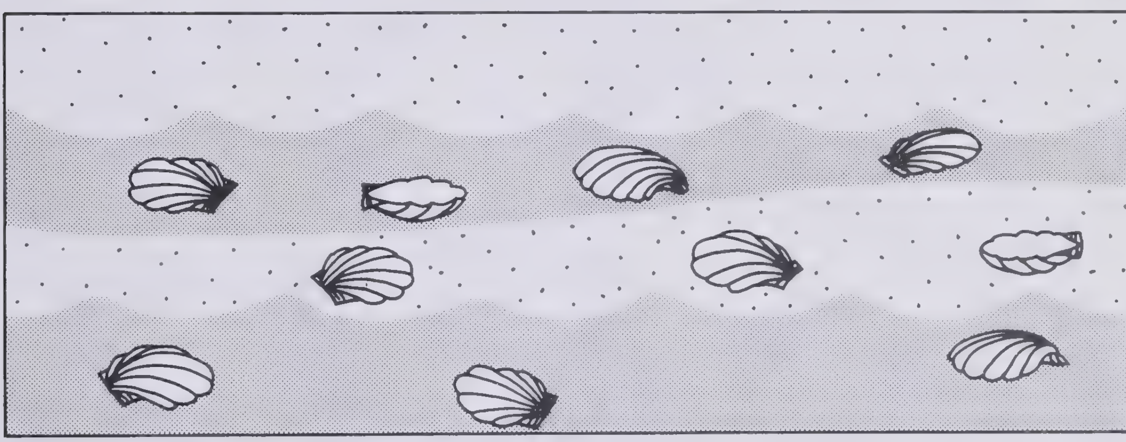


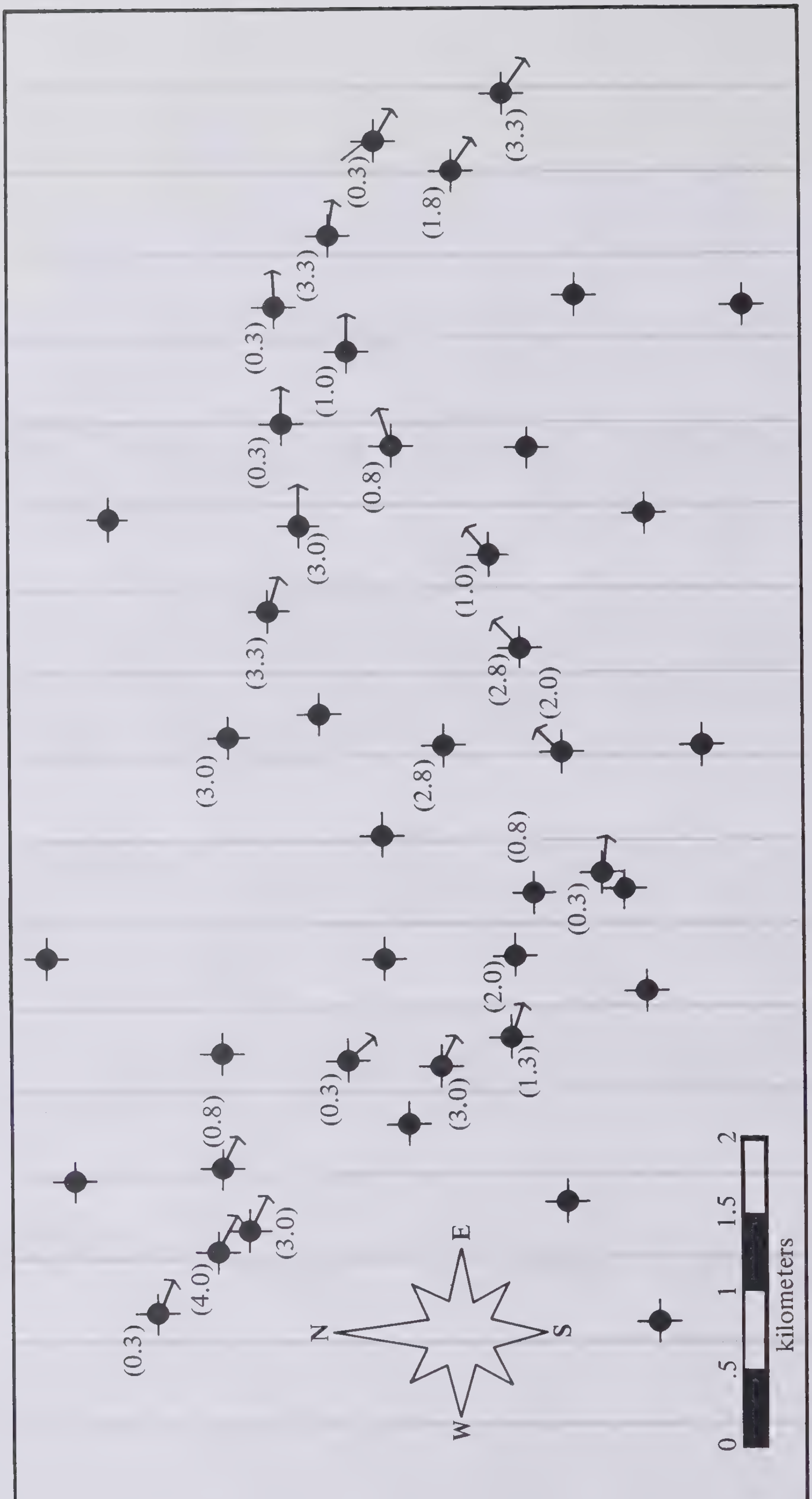

Folded Appalachians
Atlantic Coastal Plain
Piedmont
Appalachian Plateau
Blue Ridge
Interior Lowlands
Ozark
Ouachita
Rocky Mountains
Colorado
Basin and Range
Columbia
Cascades
Sierra Nevada
Coastal Ranges
Mountains
Plateaus
Plains
Plains with mountains

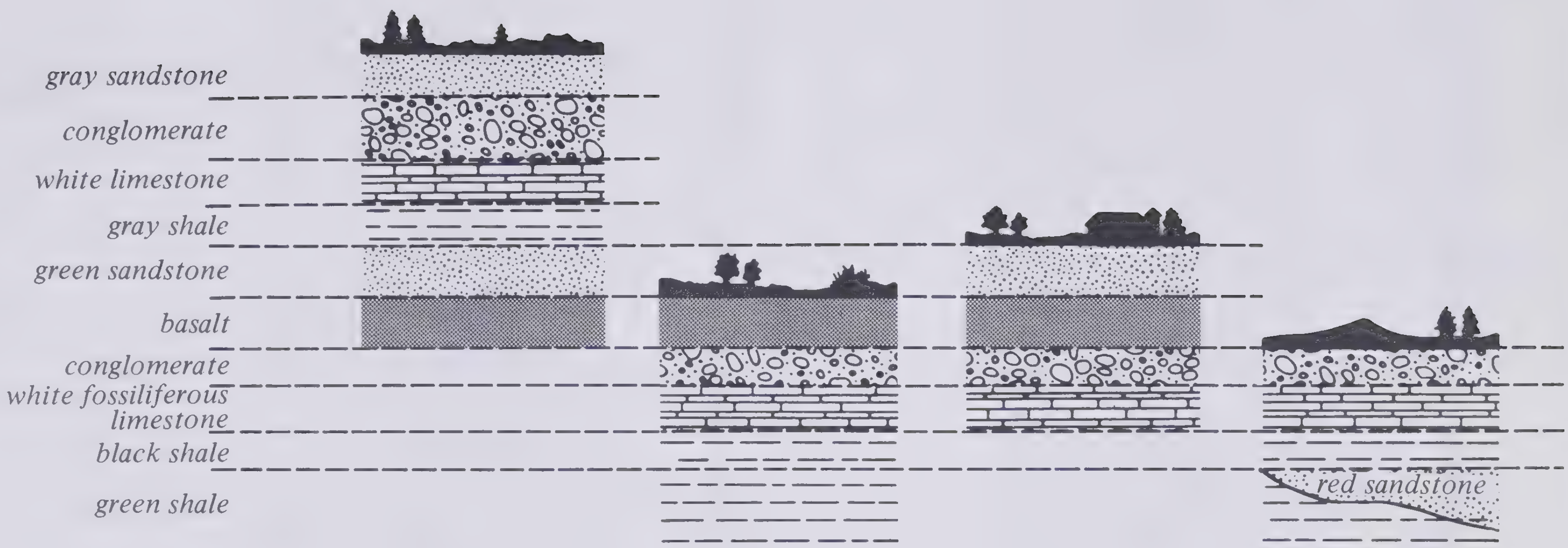

100
75
50
25
0
2
4
6
8
10
12
14
16
Per cent of original mass
Time, years × 10^9
^{232}Th
^{238}U
^{40}K
^{235}U

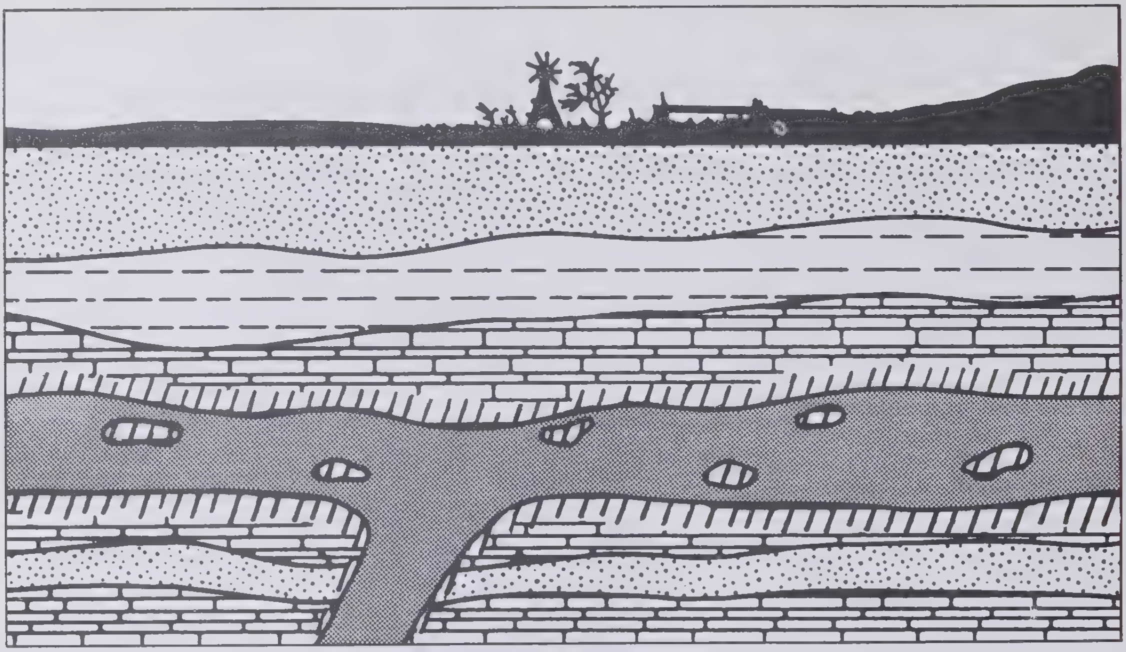


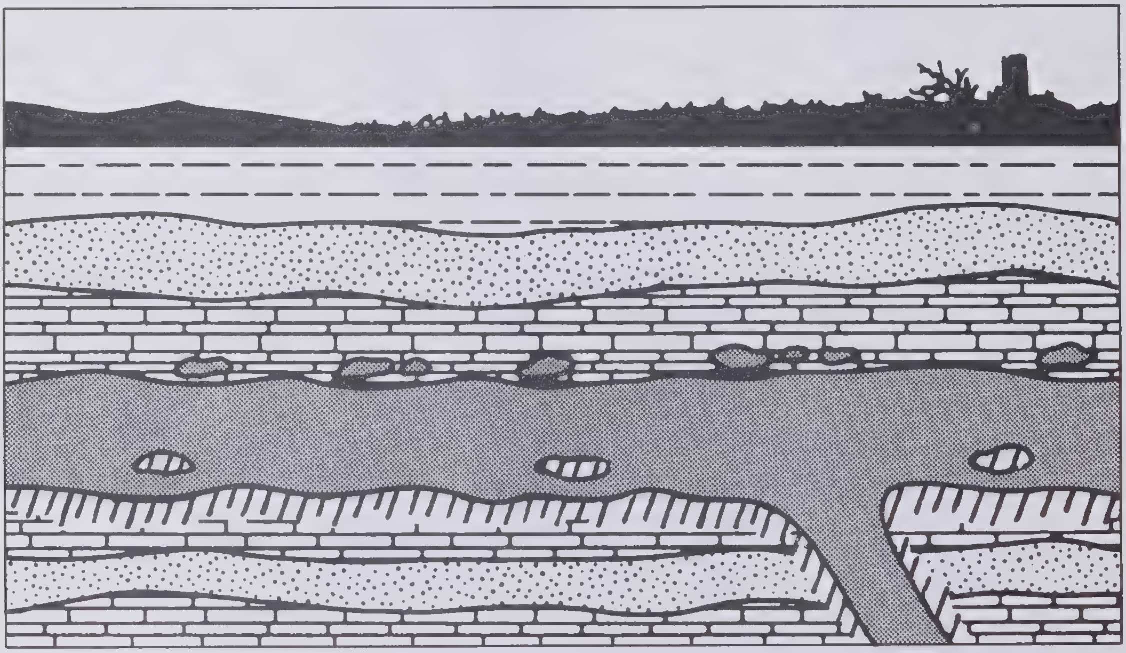


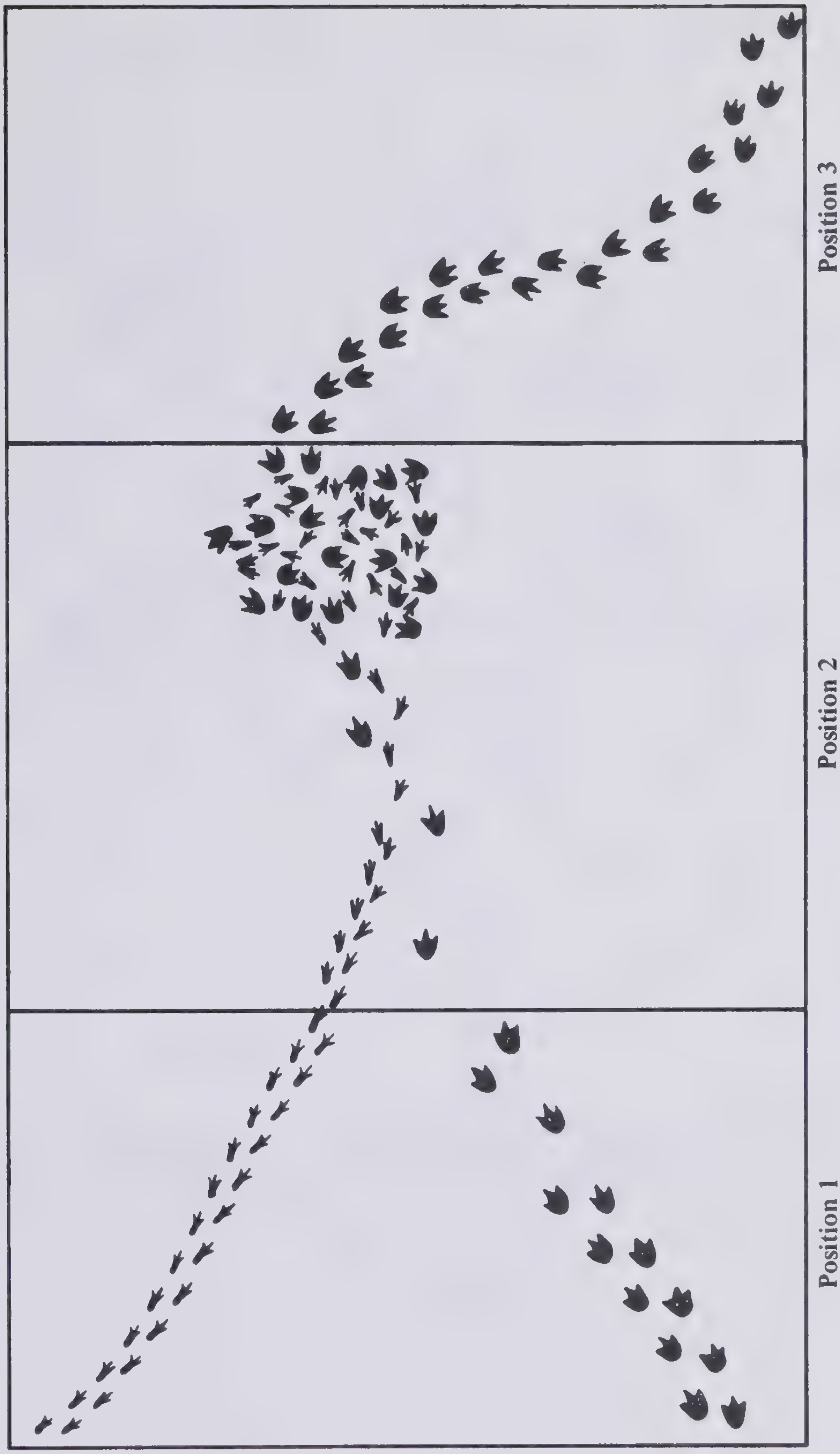



N
E
S
W
0
.5
1
1.5
2
kilometers
(0.3)
(4.0)
(3.0)
(0.8)
(0.3)
(3.0)
(1.3)
(2.0)
(0.3)
(0.8)
(2.8)
(2.0)
(3.0)
(2.8)
(3.3)
(1.0)
(3.0)
(0.3)
(0.8)
(1.0)
(0.3)
(3.3)
(0.3)
(1.8)
(3.3)

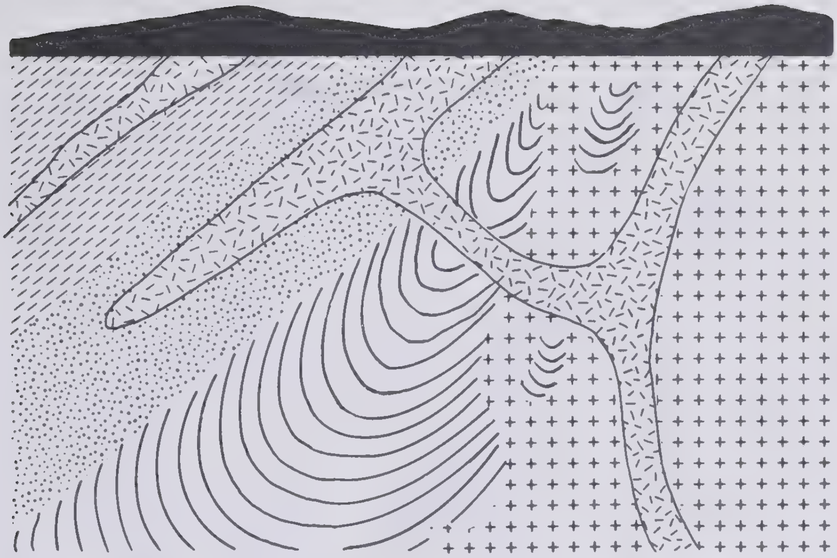

gray sandstone
conglomerate
white limestone
gray shale
green sandstone
basalt
conglomerate
white fossiliferous limestone
black shale
green shale
red sandstone

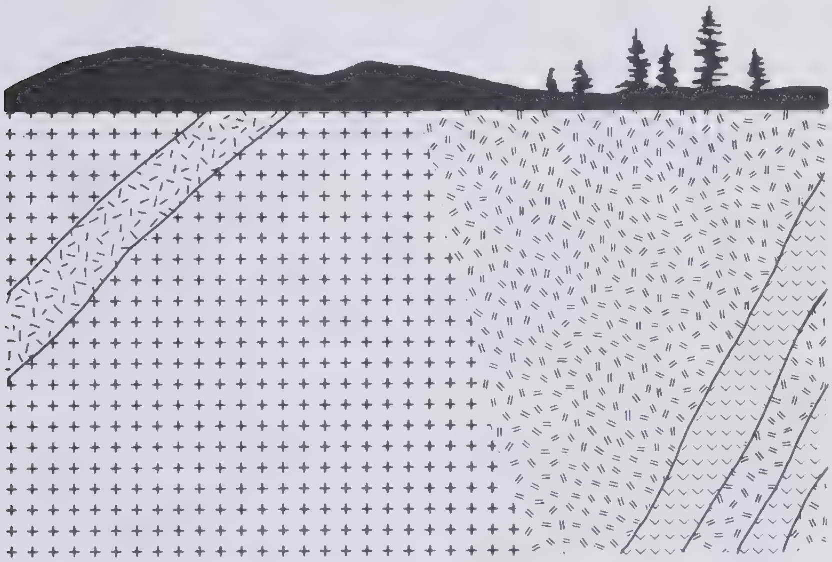


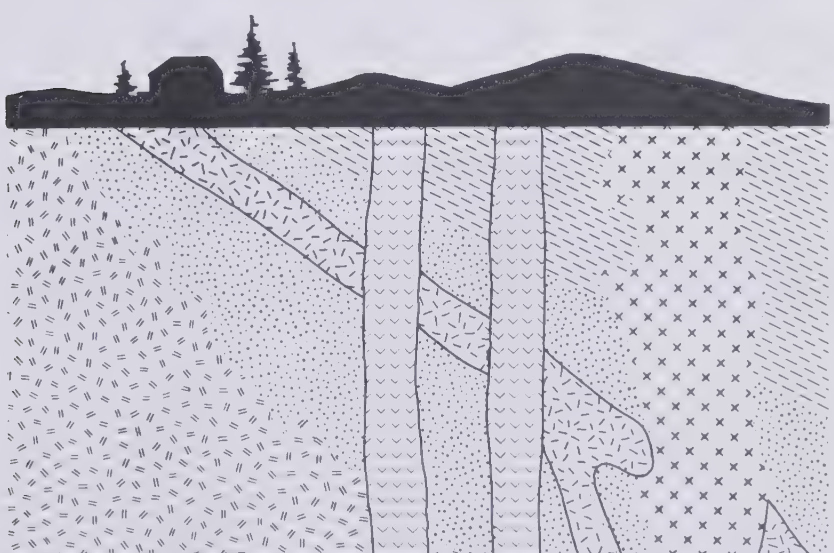


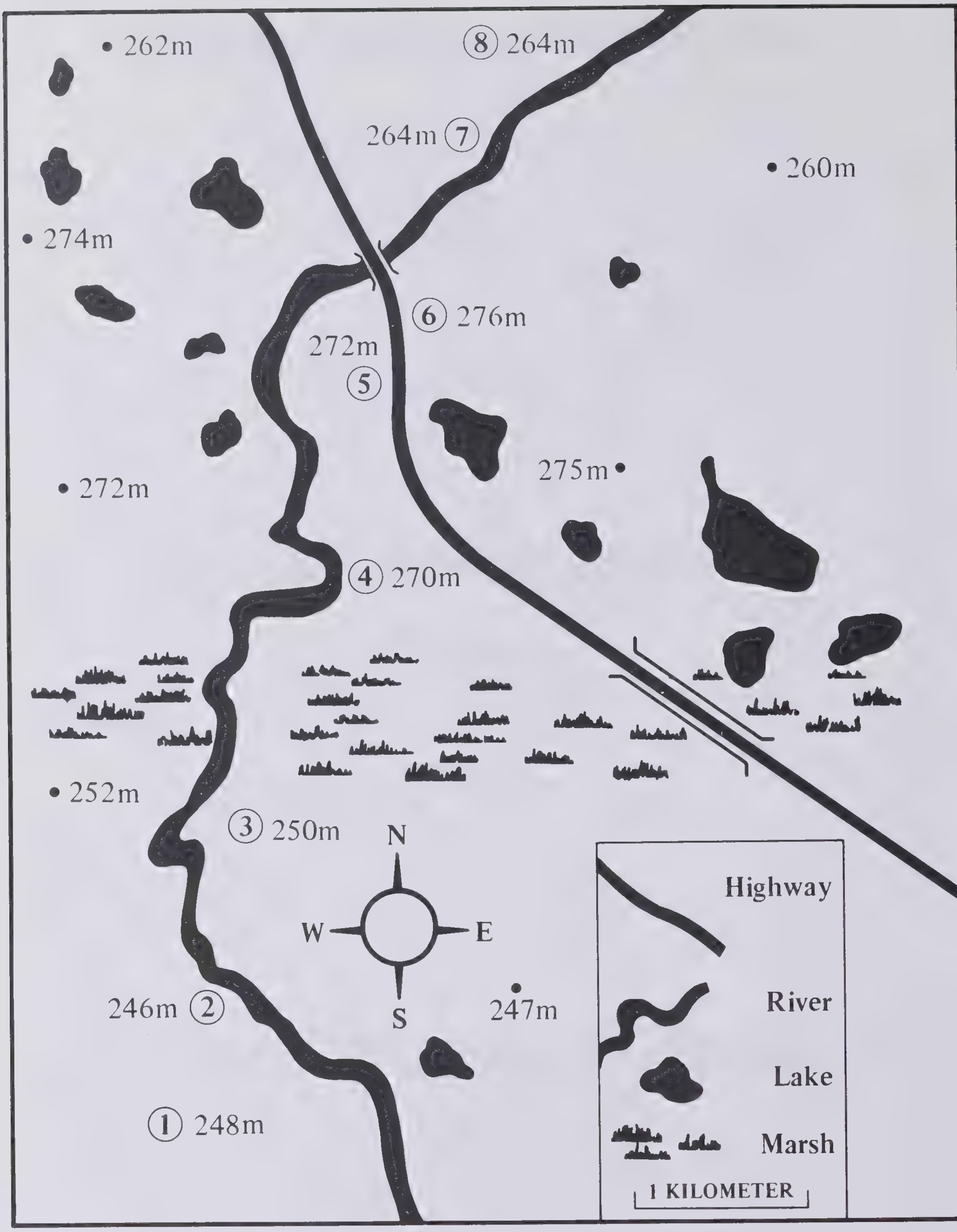

Position 3
Position 2
Position 1

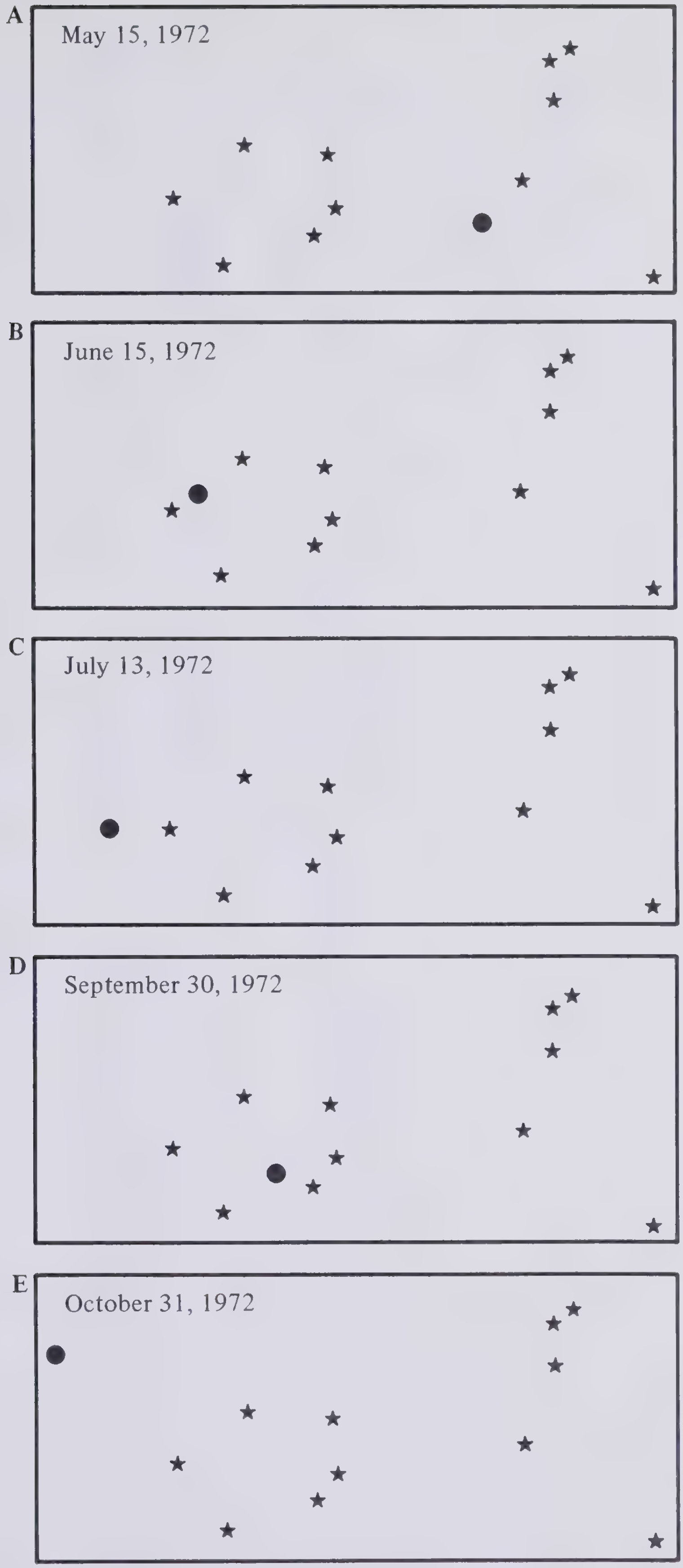

reptiles
mammals
insects
amphibians
fish
crustaceans
arachnids
conifers
brachiopods
mollusks
ferns
echinoderms
vertebrates
worms
sponges
horse-
tails
protozoans
coelenterates
bacteria
primitive plants
algae
first living organisms

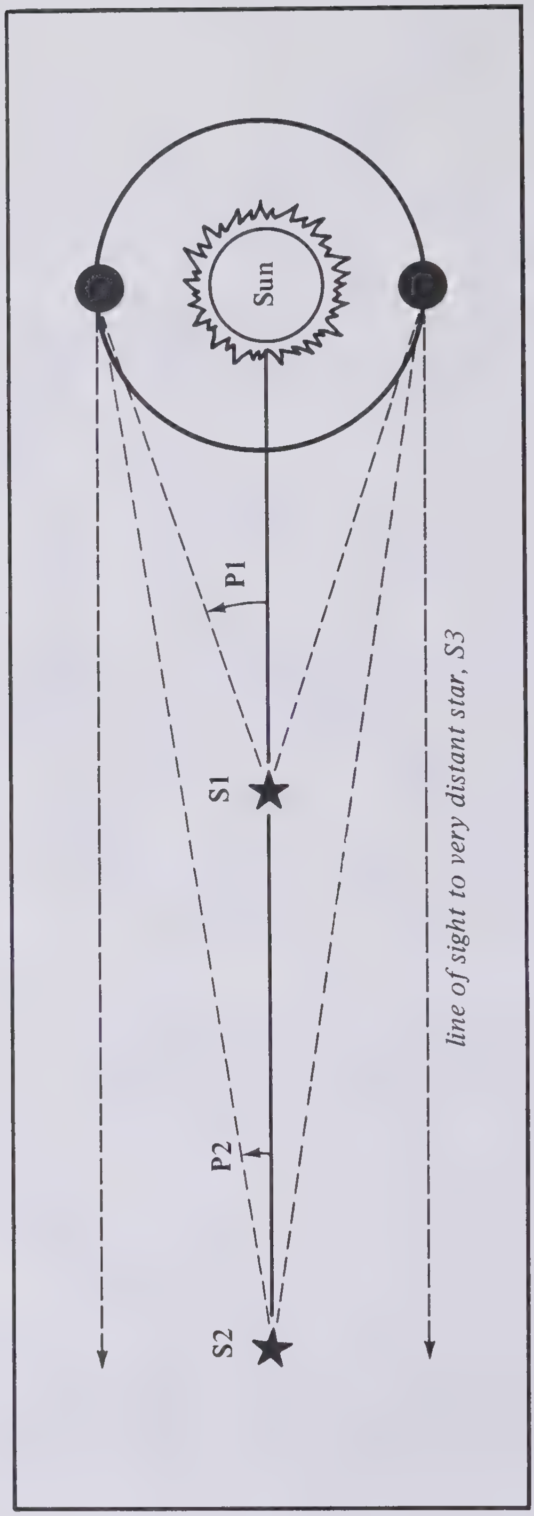


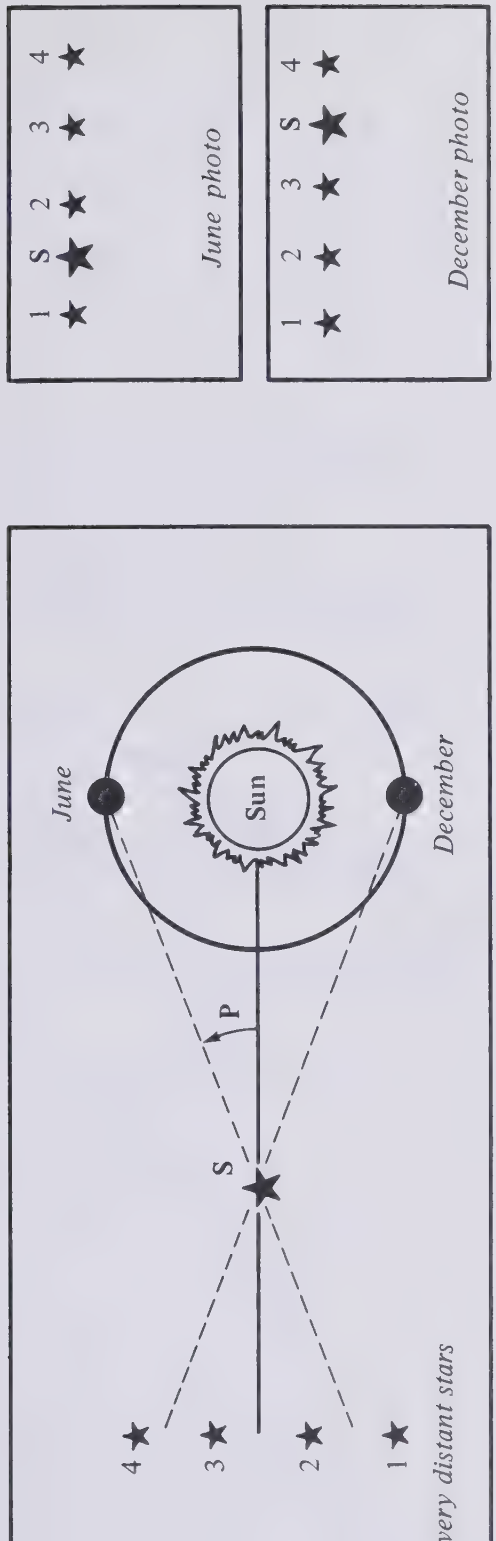




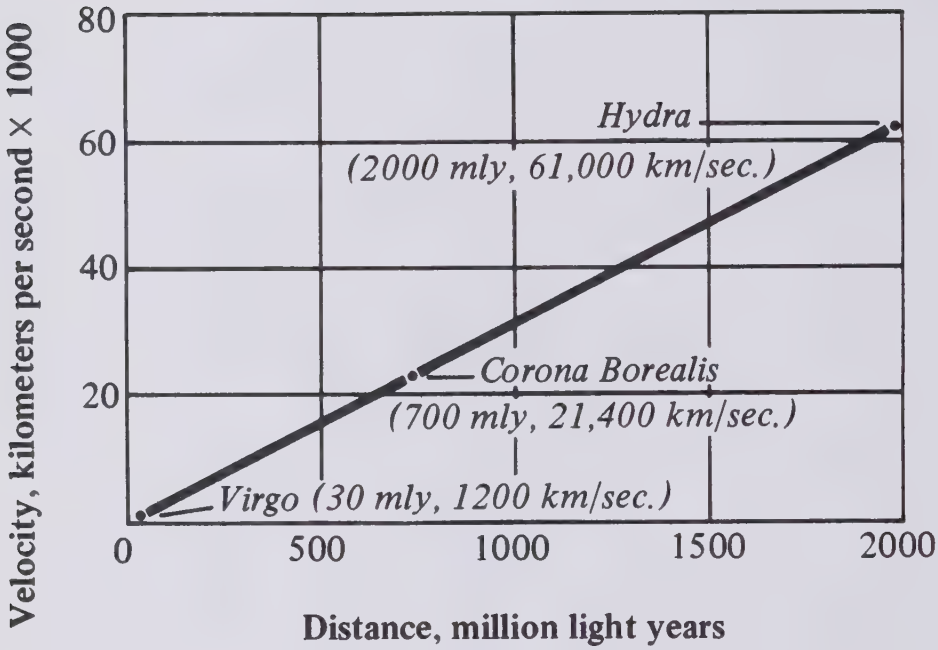

262m
8 264m
264m 7
260m
274m
6 276m
272m
5
275m
272m
4 270m
252m
3 250m
N
W
E
S
246m 2
247m
1 248m
Highway
River
Lake
Marsh
1 KILOMETER


A
May 15, 1972
B
June 15, 1972
C
July 13, 1972
D
September 30, 1972
E
October 31, 1972


Sun
P1
S1
P2
S2
line of sight to very distant star, S3



very distant stars
1
2
3
4
S
P
June
December
Sun
June photo
December photo


Velocity, kilometers per second × 1000
80
60
40
20
0
500
1000
1500
2000
Hydra
(2000 mly, 61,000 km/sec.)
Corona Borealis
(700 mly, 21,400 km/sec.)
Virgo (30 mly, 1200 km/sec.)
Distance, million light years

Decision Form

NAME ______________________

GROUP ______________________

Imagine that you belong to a space crew scheduled to rendezvous with a mother ship on the lighted surface of the moon. However, mechanical difficulties have forced your ship to crash-land 200 miles from the rendezvous point. The rough landing damaged much of the equipment aboard.

Survival depends on reaching the mother ship. Below are listed the 15 items left intact after landing. Your task is to rank them in terms of their importance to your crew in its attempt to reach the rendezvous point, 200 miles away. Place number 1 by the most important item, number 2 by the second most important, and so on through number 15, the least important.

_______ Box of matches

_______ Food concentrate

_______ 50 feet of nylon rope

_______ Parachute silk

_______ Portable heating unit

_______ Two .45 calibre pistols

_______ One case dehydrated milk

_______ Two 100-pound tanks of oxygen

_______ Stellar map of the moon's constellations

_______ First aid kit containing injection needles

_______ Solar powered FM receiver-transmitter.

_______ Five gallons of water

_______ Life raft

_______ Magnetic compass

_______ Signal flares

Group Summary Sheet

	Name										GROUP CHOICE
Matches											
Food											
Rope											
Parachute											
Heating unit											
Pistols											
Dry milk											
Oxygen											
Map											
First aid kit											
Radio											
Water											
Life raft											
Compass											
Signal flares											
SCORE											

GROUP SCORE
(average) ____________

Data Sheet

Group	Average individual score	Range	Group score	Difference between average individual & group

Class Consensus Score ________

Highest Individual Score ________

Lowest Individual Score ________

Appendix B. Mathematical Helps

Dimensions and Units

Individual units of measurement, such as 5 grams, 10 seconds, 13 centimeters, or 7 degrees Celsius are comparatively easy for most students to understand and record correctly. Frequently, however, calculations involving units cause difficulty. The technique of writing the units in the formula and then handling them as though they were constants is one of the easiest ways of keeping track of units.

An example of a calculation involving units is density, defined as mass divided by volume. If the mass is in grams and the volume is in cubic centimeters, then the unit of density is grams per cubic centimeter.

$$D = \frac{M}{V}, \text{ or } D = \frac{g}{cm^3}$$

Another example of mathematical manipulations students will make with units is in Investigation 1–2, Measuring the Earth. The proportion is:

$$\frac{\text{Distance around globe}}{\text{distance between sticks}} = \frac{\text{Angle of full circle A}}{\text{Angle a}}$$

or

$$\frac{D}{d} = \frac{A}{a}$$

D is the unknown quantity. Its unit depends on the units of d, A, and a. If d is measured in centimeters, A in degrees, and a in degrees, then you can write:

$$\frac{D}{cm} = \frac{\text{degrees}}{\text{degrees}}$$

or

$$D = \frac{cm \times \text{degrees}}{\text{degrees}}$$

The units that are the same (degrees) cancel, so the unit for D is centimeters.

This method provides a good check on your formula. If any units except those in the answer fail to cancel, either you have set up the problem wrong or you have made a mistake somewhere.

It helps keep things simple if, at the start, you convert the measurements in a problem to units that can cancel. In the previous problem if A had been measured in degrees and a in minutes of a degree, the units would not have canceled. D would be expressed in an unconventional unit:

$$\frac{cm \times \text{degrees}}{\text{minutes of a degree}}$$

The easiest way to convert units of measurement is to follow the same procedure of treating units as if they were constants. If you want to find out how many kilometers 35 millimeters is, for instance, you could set up this formula:

$$35 \text{ mm} \times \frac{0.001 \text{ m}}{\text{mm}} \times \frac{0.001 \text{ km}}{\text{m}} = 35 \times 10^{-6} \text{ km}$$

This is a two-step conversion. The first fraction converts millimeters to meters; the second converts meters to kilometers.

You can change 0.015 kilometers to millimeters just the opposite way.

$$0.015 \text{ km} \times \frac{1000 \text{ mm}}{\text{m}} \times \frac{1000 \text{ m}}{\text{km}} = 0.015 \times 10^{6} \text{ mm}$$

Even more complicated conversions can be accomplished without confusion if you keep track of the units. To change 5.0 grams per cubic centimeter to units of kilogram per cubic meter, do each unit separately:

$$5.0 \text{ g} \times \frac{0.001 \text{ kg}}{\text{g}} = 5 \times 10^{-3} \text{ kg}$$

$$cm^3 \times \frac{m^3}{10^6 \text{ cm}^3} = 10^{-6} \text{ m}^3$$

The result is:

$$\frac{5.0 \text{ g}}{cm^3} = \frac{5 \times 10^{-3} \text{ kg}}{10^{-6} \text{ m}^3} = \frac{5 \times 10^{3} \text{ kg}}{m^3}$$

Significant Figures

The accuracy of the last digit in any measurement is uncertain. This is because you don't know what the next figure would be if the dial or instrument could show it. A measurement of 19.5 might be 19.51 or it actually might be 19.55. You need to take this uncertainty into account when you work with numbers that are measurements. The results of your calculation cannot be more accurate than the measurements themselves.

Keeping track of the number of significant figures in your calculations is the way to be sure your answer reflects the amount of precision in your experiment. In most cases, the number of significant figures is the number of digits in the measurement. When zeroes are used to place the decimal, they don't count as significant figures.

Measurement	Significant Figures
1	1
1.12	3
1.123	4
1.0	2
1.0010	5
0.1	1
0.0001	1
1.0001	5

You must keep in mind that there is no way you can end up with more significant figures than you started with. Adding the weights of two objects together, for example, does not make the answer more precise than the original measurements.

5.1234 g	5 significant figures
+ 5.1222 g	5 significant figures
10.2456 g	6 significant figures

The answer must be rounded to 10.246, which has 5 significant figures.

Subtraction, in fact, may reduce the number of significant figures.

5.1234 g	5 significant figures
−5.1222 g	5 significant figures
0.0012 g	2 significant figures

In any calculation the result can have only as many significant figures as the least precise measurement in the problem:

$$\frac{(4.654 - 4.632) \times 2.127}{1.12}$$
$$= \frac{0.022 \times 2.127}{1.12}$$
$$= 4.2$$

You can simplify many calculations with measurements by dropping the non-significant digits before you do the arithmetic.

Powers of Ten

Very large and very small numbers with lots of zeroes are hard to read and write correctly. They are unwieldy to use in even the simplest arithmetic problems.

A more compact way to write these numbers uses the powers of ten. For example, 1000 can be written as 1×10^3, where three is the exponent, the number of tens that must be multiplied together $(10 \times 10 \times 10)$ to make 1000. A quick way to find the exponent is to count how many digits you must move the decimal to get the original number. In this system 1000 also could be written as 10×10^2, or even as 0.1×10^4. Here are some other examples of large numbers written as powers of ten.

$$20{,}000{,}000{,}000 = 2 \times 10^{10}$$
$$643{,}700{,}000 = 64.37 \times 10^7$$
$$720{,}000 = 7.2 \times 10^5$$

Numbers less than one are written with negative powers of ten: $0.00001 = 1 \times 10^{-5}$. You find the powers of ten the same way.

$$0.000001 = 1 \times 10^{-6}$$
$$0.0141 = 1.41 \times 10^{-2}$$
$$0.007364 = 73.64 \times 10^{-4}$$

Calculations using numbers written this way are not difficult. In multiplying, the exponents are added together. The rest of the number is multiplied as usual.

$$(4 \times 10^4)(2.3 \times 10^5) = 8.6 \times 10^9$$
$$(2 \times 10^{-5})(7.1 \times 10^{-2}) = 14.2 \times 10^{-7}$$
$$(3 \times 10^6)(1.2 \times 10^{-4}) = 3.6 \times 10^2$$

In dividing, the exponents are subtracted.

$$(6 \times 10^3) \div (3 \times 10^6) = 2 \times 10^{-3}$$
$$(5 \times 10^{-2}) \div (2 \times 10^{-8}) = 2.5 \times 10^6$$
$$(2.4 \times 10^{-6}) \div (8 \times 10^{-3}) = .3 \times 10^{-9}$$

Appendix C. Materials and Supplies

Kits

A large variety of equipment and materials has been developed for the laboratory investigations in *Investigating the Earth*. These supplies are assembled in Laboratory Kits that contain the equipment and materials for an investigation. Guides to each investigation list the Kits required and also substitutions for teachers not using the Kit materials. Information about the Kits is available from Hubbard Scientific Company, P.O. Box 105, Northbrook, Ill. 60062.

Kit	*Quantity for 30 students*
Acceleration Kits	10
Air Mass Generator Kits	10
Basic Fossil Kits	10
Cloud Chamber Kits	15
Contour Model Kits	15
Coriolis Kits	10
Density Kits	10
Earth Materials Kit	1
Earthquake Watch Kit	1
Evaporation Kits	15
Galaxy Card Kits	15
Geologic History Kits	10
Globe Kits	15
Heat Transfer Kits	15
Landform Map Kits	15
Magnetic Sphere Kits	15
Molecular Model Kits	15
Plastic Column Kits	15
Radiation Kits	15
Screen Sieve Kit	1
Soil Profile Kits	10
Spectroscope Kits	15
Sphere Dynamics Kits	15
Stream Table Kits	4
Stereo Photo Kits	15
Variation and Evolution Kits	8
Teacher's Kit	1

Investigation equipment

Equipment and supplies required for each investigation are listed here along with the quantity required for a class of 30 students. The lists assume that water and paper towels are readily available in the classroom.

Investigation	Quantity
1–2 Measuring the Earth	
Kit Materials	
Globe Kit	15 kits
globe, 20-cm diameter	
flexible ruler	
rods or toothpicks up to 10 cm long	
clay or 2 suction cups to attach rods to globe	
protractor	
Radiation Kit	15 kits
lamp, 200-watt bulb with reflector	
Other Materials	
cardboard or stiff paper, 20 cm square	15 pieces
string, 100 cm	15 pieces

Investigation	Quantity
1–7 Investigating the sun's path — Sun Watch	
Kit Materials	
Globe Kit	15 kits
transparent plastic hemisphere	
external protractor to fit hemisphere	
Other Materials	
marking crayon or pen	15 pens
cardboard or stiff paper, 30 cm square	15 pieces
masking tape	1 roll
2–3 Investigating rocks and minerals	
Kit Materials	
Earth Materials Kit	15 kits
Granite	
porphyry	
quartz sandstone	
basalt	
limestone	
gneiss	
Teacher's Kit	1 kit
magnifier	
crushed granite	
Other Materials	
stereomicroscope (optional)	1–6 microscopes
2–4 Investigating mass, volume, and density	
Kit Materials	
Density Kit	15 kits
aluminum bar, 8 × 3 × 1 cm	
aluminum cubes, 1 cm on a side	
steel ball, 1 cm	
glass ball, 1 cm	
ruler, 15 cm	
Other Materials	
identical opaque bottles with caps	2 bottles
sand, enough to fill one bottle	
a bottle or jar, tall and narrow	1 jar
alcohol, isopropyl	4 liters
glycerine	10–20 ml
oil, such as corn or mineral oil	10–20 ml
food coloring	
oil-base modeling clay	750 g
pebbles	15 pebbles
beakers, 250 ml	30 beakers
ice cubes	60 cubes

3–2 Investigating patterns of change — Weather Watch

Other Materials	
rain gauge or can and graduated cylinder	1 gauge
anemometer, wind meter, or wind gauge	1 gauge
barometer	1 barometer
thermometer	1 thermometer
data sheets or white shelf paper	30 sheets
maximum-minimum thermometer (optional)	1 thermometer
psychrometer	1 psychrometer
Cloud Code Chart (see page xi)	1 chart

3–3 Investigating patterns of change — Earthquake Watch

Kit Materials	
Earthquake Watch Kit	1 kit
Pacific-centered Mercator world map	
map pins, 3 colors	300 pins
Other Materials	
epicenter data (see page xi)	

3–5 Investigating flow and change in energy (Part A)

Kit Materials	
Radiation Kit	10 kits
shiny metal can, 6 oz	
black metal can, 6 oz	
insulating lids with slits, 2	
thermometers, range −20°C to 50°C, 2	
lamp, 200 watts, without reflector	
Other Materials	
graph paper	30 sheets

(Part B)

Kit Materials	
Heat Transfer Kit	15 kits
insulated containers, 2	
insulating lids with slits, 2	
U-shaped aluminum transfer bar	
thermometers, range −10°C to 100°C, 2	
Other Materials	
boiling water	3 liters
graph paper	30 sheets

Investigation	Quantity
3–9 Investigating the behavior of a falling object	
Kit Materials	
Acceleration Kit	10 kits
time interval marker	
interval marker tape	
carbon disks	
C-clamp	
weight	
Other Materials	
dry cell, 1.5 volts	10 batteries
metric ruler	10 rulers
scissors	10 scissors
glue or rubber cement	2 jars
construction paper, dark-colored	30 sheets
3–12 Investigating magnetic fields	
Kit Materials	
Magnetic Sphere Kit	15 kits
plastic sphere with a magnet inside	
round, flat, covered plastic container	
Other Materials	
magnetic compass	15 compasses
iron filings	
4–6 Investigating the Coriolis effect	
Kit Materials	
Coriolis Effect Kit	15 kits
circular tray or large pie tin	
turntable	
sand, 100–500 ml	
steel ball, 1–4 cm diameter	
ramp, at least 5 cm long	
4–7 Investigating currents	
Kit Materials	
Plastic Column Kit	15 kits
transparent plastic tube, 80 cm, with stopper	
Contour Model Kit	15 kits
transparent plastic box	
Other Materials	
ring stand and clamp	15 sets
test tubes	30 tubes

Investigation	Quantity
hot plate or other heat source	15 sources
beakers, 100 ml	30 beakers
thermometers, range −20°C to 50°C	45 thermometers
thermometers, range −10°C to 110°C	15 thermometers
paper cup or plastic bag	15 cups
crushed ice	5 liters
table salt	2–5 lbs
food coloring	
5–2 Investigating evaporation	
Kit Materials	
Evaporation Kit	15 kits
equal-arm balance	
sponge	
Radiation Kit	15 kits
lamp, 200 watt bulb with reflector	
Other Materials	
plastic sandwich bags	30 bags
transparent plastic sheets	30 sheets
food coloring	
graph paper	60 sheets
alcohol, isopropyl (optional)	
5–3 Investigating energy changes during evaporation	
Other Materials	
beaker, 150 ml or larger	15 beakers
thermometer, range −10°C to 110°C	15 thermometers
ring stand with ring clamp and wire gauze, or a tripod	15 sets
hot plate or other heat source	15 sources
crushed ice	3 liters
graph paper	30 sheets
safety glasses (optional)	30 pairs
5–9 Investigating cumulus cloud formation	
Kit Materials	
Radiation Kit	15 kits
shiny metal can	
Other Materials	
sling psychrometer	15 psychrometers
thermometer, range −20°C to 50°C	15 thermometers
crushed ice	1 liter

Investigation	Quantity
5–11 Investigating an air mass	
Kit Materials	
Air Mass Generator Kit	15 kits
hollow plastic tube, about 5 cm × 50 cm	
hollow container for base	
Other Materials	
ice	3 liters
6–1 Investigating radiant energy	
Kit Materials	
Radiation Kit	10 kits
black metal cans, 4	
insulating lids, 4	
lamp with 200-watt bulb	
Other Materials	
thermometers, range −20°C to 50°C	40 thermometers
meterstick	10 sticks
6–5 Investigating land and water temperatures	
Kit Materials	
Radiation Kit	10 kits
lamp, 200-watt bulb with reflector	
Other Materials	
containers, 500 ml	20 containers
thermometers, range −20°C to 50°C	40 thermometers
dry sand or soil	
ring stand	10 stands
7–10 Investigating the climates of an imaginary continent	
Other Materials	
map of the imaginary continent	30 maps
8–3 Investigating the movement of water in earth	
Kit Materials	
Plastic Column Kit	15 kits
transparent plastic tube, 80 cm × 35 mm	
cap with drain hose	
hose clamp or hose cock	
cap screen	

Investigation		Quantity
	Teacher's Kit	1 kit
	beads, 4 mm, 6 mm, 8 mm	500 ml of each
	Other Materials	
	ring stand and clamp	10 sets
	beakers, 600 ml	20 beakers
	graduated cylinder, 100 ml	10 graduates
	paper towels	
8–9	**Investigating a flood**	
	Other Materials	
	graph paper	30 sheets
9–3	**Investigating products of weathering**	
	Kit Materials	
	Earth Materials Kit	15 kits
	soil sample, topsoil	
	soil sample, subsoil	
	granite, coarse-grained	
	granite, crushed, 150 ml	
	Teacher's Kit	1 kit
	magnifiers, 15	
	Soil Profile Kit	15 kits
	transparent plastic tubes with caps, 2	
	Other Materials	
	teasing needles	15 needles
	microscope (optional)	1–6 microscopes
9–7	**Investigating stream erosion**	
	Kit Materials	
	Stream Table Kit	4 kits
	trough, about 1 m × 5 cm radius	
	siphon tube with clamp, about 2 m × 1 cm diameter	
	support to raise one end of trough	
	Globe Kit	4 kits
	protractor	
	Other Materials	
	gravelly sand	2 liters
	catch buckets	10 buckets
	timer	4 timers
10–1	**Investigating the deposition of sediments**	
	Kit Materials	
	Plastic Column Kit	15 kits
	transparent plastic tube, 80 cm × 35 mm, with cap	

Investigation		Quantity
	Screen Sieves Kit	1 kit
	Other Materials	
	ring stand and clamp	15 sets
	sorted sediments	300 ml each size
	unsorted sediments	2 liters
	clock with second hand	1 clock
10–4	**Investigating turbidity currents**	
	Kit Materials	
	Plastic Column Kit	15 kits
	transparent plastic tube, 80 cm × 35 mm, with cap	
	Other Materials	
	ring stand and clamp	15 sets
	slurry material	2 liters
	test tubes, large	45 tubes
	clock with second hand	1 clock
	marking crayon, colored chalk, or lipstick	15 crayons
11–1	**Investigating inland marine sediments**	
	Other Materials	
	graph paper	30 sheets
11–5	**Investigating earthquakes**	
	Other Materials	
	marking crayons	
	transparent plastic sheet or tracing paper	30 sheets
	graph paper	
12–2	**Using a geologic map to study rocks**	
	Other Materials	
	modeling clay, several colors (optional)	
	geologic maps of any areas (optional)	
12–4	**Investigating plutonic rocks**	
	Kit Materials	
	Earth Materials Kit	1 kit
	pink granite	
	gray granite	
	diorite	
	gabbro	
	granodiorite (optional)	
	syenite (optional)	

Investigation		Quantity
	peridotite (optional)	
	dunite (optional)	
	Teacher's Kit	1 kit
	magnifiers	
	Other Materials	
	teasing needles	15 needles
	stereomicroscope (optional)	1–6 microscopes
12–7	**Investigating metamorphic rocks**	
	Kit Materials	
	Earth Materials Kit	1 kit
	marble and limestone	
	quartzite and sandstone	
	slate and shale	
	mica schist	
	granite gneiss and granite	
	phyllite	
	Teacher's Kit	1 kit
	magnifiers	
	Other Materials	
	mica specimens (optional)	15 specimens
	stereomicroscope (optional)	1–6 microscopes
12–10	**Investigating volcanic rocks**	
	Kit Materials	
	Earth Materials Kit	1 kit
	felsite (non-porphyritic)	
	basalt (dense)	
	basalt (vesicular-scoria)	
	rhyolite (porphyritic)	
	andesite	
	obsidian	
	pumice	
	salol (optional)	
	Teacher's Kit	1 kit
	magnifiers	
	Other Materials	
	stereomicroscope (optional)	1–6 microscopes
13–1	**Investigating the inside of a sphere**	
	Kit Materials	
	Sphere Dynamics Kit	15 kits
	two spheres of identical size and mass,	

Investigation		Quantity
	one with uniform mass, one with mass concentrated near the surface	
13–4	**Locating the epicenter of an earthquake**	
	Kit Materials	
	Globe Kit	15 kits
	globe	
	Other Materials	
	graph paper	30 sheets
	marking crayons	15 crayons
	string	
14–2	**Investigating maps as models**	
	Kit Materials	
	Contour Model Kit	15 kits
	transparent box with lid	
	plastic volcano model	
	Stereo Photo Kit (optional)	15 kits
	stereo viewer	
	stereo atlas	
	Other Materials	
	marking crayons	15 crayons
	clear plastic sheets	15 sheets
	masking tape	1 roll
	food coloring (optional)	
14–5	**Investigating areas of erosion and deposition**	
	Kit Materials	
	Stream Table Kit	4 kits
	tray with drain at one end, about 122 × 36 × 9 cm	
	siphon tube with clamp, about 2 m × 1 cm diameter	
	support to raise one end of tray	
	Other Materials	
	soil	4 buckets
	catch bucket	4 buckets
	Polaroid camera (optional)	1 camera
14–10	**Investigating regional landscapes**	
	Kit Materials	
	Stereo Photo Kit	15 kits
	stereo viewer	
	stereo atlas	

Investigation		Quantity
	Landform Map Kit	15 kits
	map	
	Other Materials	
	clear plastic sheets	30 sheets
	grease pencils or water soluble markers	15 markers
15–5	**Investigating radioactive decay rates**	
	Kit Materials	
	Contour Model Kit	15 kits
	transparent plastic box	
	Teacher's Kit	1 kit
	markers	1500 markers
	Other Materials	
	graph paper	30 sheets
15–8	**Investigating the Geologic Time Scale**	
	Kit Materials	
	Teacher's Kit	1 kit
	paper tape	
	Other Materials	
	meterstick	1
16–4	**Investigating an ancient stream channel**	
	Other Materials	
	map of the stream channel	30 maps
	metric ruler	30 rulers
16–5	**Investigating puzzles in the earth's crust**	
	Kit Materials	
	Basic Fossil Kit	10 kits
	plastic replicas of fossils	
	Other Materials	
	rock outcrop diagrams	60 copies
	real fossils (optional)	
16–8	**Interpreting a chapter in earth history**	
	Kit Materials	
	Geologic History Kit	10 kits
	modeling clay, 4 colors	2½ pounds each
	wooden roller	
	Other Materials	
	powder, flour, or plastic film	
	knife or cheese cutter	10 knives

Investigation		Quantity
Optional Field Trip: Investigating earth history in the field		
	Other Materials	
	hand lenses	
	measuring tapes	
	rock hammers and chisels	
	plastic bottles of dilute hydrochloric acid	
	compass	
	maps of the field-trip area	
	rock collecting bags	
	notebook	
	first aid kit	
	safety glasses	
17–7	**Investigating casts and molds**	
	Other Materials	
	fast-drying plaster	15 pounds
	container for mixing	15 containers
	food coloring	
	stirring device	15 stirrers
	aluminum pie plate or milk carton	15 plates
	objects to cast	
	petroleum jelly or non-detergent soap solution	
17–10	**Investigating variation and evolution**	
	Kit Materials	
	Variation and Evolution Kit	8 kits
	molded plastic fossil sheets	
	calipers	
	Other Materials	
	metric ruler	8 rulers
	masking tape	1 roll
17–15	**Investigating population growth**	
	Other Materials	
	small, uniformly shaped objects (corn, beans, or beads)	large number
	paper cups or small beakers	30 cups
	beaker, 250 ml or 400 ml	10 beakers
18–1	**Investigating Precambrian rocks**	
	Other Materials	
	transparency of Figure 18–1	1 transparency
18–8	**Investigating an Ice Age Puzzle**	
	Other Materials	
	graph paper	30 sheets

Investigation		Quantity
19–2	**Investigating landscapes on the moon**	
	Kit Materials	
	Stereo Photo Kit	15 kits
	moon photograph from stereo atlas	
	Teacher's Kit	1 kit
	map of Monte Appenninus region of the moon	
	Other Materials	
	transparent plastic sheet	15 sheets
	marking crayons	15 crayons
19–7	**"Lost on the Moon"**	
	Other Materials	
	Student Decision Forms	60 copies
	Group Summary Sheets	12 copies
20–1	**Investigating interplanetary distances**	
	Other Materials	
	paper tape	5 rolls
	meterstick	15 sticks
20–3	**Motions and phases of Planet X**	
	Other Materials	
	styrofoam sphere, 3 to 10 cm diameter,	8 balls
	lamp with 15- or 20-watt bulb	8 lamps
22–6	**Classifying galaxies**	
	Kit Materials	
	Galaxy Card Kit	15 kits
	photos of nine different galaxies	

Appendix D. Enrichment materials

Books and pamphlets

The *Geology and Earth Sciences Sourcebook for Elementary and Secondary Schools* was produced by the American Geological Institute, sponsor of *Investigating the Earth.* This newly-revised resource book contains a variety of ideas and assistance for earth science teachers. Demonstrations, classroom activities, teaching aids, earth science information, and reference sources are arranged by subject matter. The *Sourcebook* is available from Holt, Rinehart & Winston, Inc., New York.

Leading earth science specialists prepared a series of pamphlets for the Earth Science Curriculum Project, originator of the *Investigating the Earth* program. The pamphlets are designed to assist earth science teachers in directing field work and outdoors observations. Each pamphlet contains authentic photographs and background data, activity suggestions, and lists of materials needed. The following titles are available from Houghton Mifflin Company individually or in a set containing all ten.

Field Guide to Rock Weathering, by Robert E. Boyer
Field Guide to Soils, by Henry Foth and Hyde S. Jacobs
Field Guide to Layered Rocks, by Tom Freeman
Field Guide to Fossils, by James R. Beerbower
Field Guide to Plutonic and Metamorphic Rocks, by William D. Romey
Color of Minerals, by George Rapp, Jr.
Field Guide to Beaches, by John H. Hoyt
Field Guide to Lakes, by Jacob Verduin
Field Guide to Astronomy Without a Telescope, by William A. Dexter
Meteorites, by Carleton B. Moore

The ESCP Reference Series pamphlets summarize the resources and materials available to earth science teachers. The titles in the series, available from Prentice-Hall, Inc., Englewood Cliffs, N.J., are:

RS-1 *Sources of Earth Science Information,* 1964, W. H. Matthews, III.
RS-2 *Selected References for Earth Science Courses,* 1964, W. H. Matthews, III.
RS-3 *Selected Earth Science Films,* 1964, Wakefield Dort, Jr.
RS-4 *Selected Maps and Earth Science Publications of the States and Provinces of North America,* 1965, W. H. Matthews, III.
RS-5 *Free Materials for Earth Science Teachers,* 1965, W. H. Matthews, III, and R. B. Bartholomew.
RS-6 *Planetariums, Observatories, and Earth Science Exhibits,* 1965, W. H. Matthews, III.
RS-7 *Topographic Maps — Their Use and Interpretation,* 1967, Malcolm P. Weiss.
RS-8 *Guide to Geological Field Trip Guidebooks for North America,* 1967, Donald H. Lokke.
RS-9 *Basic Data and the Water Budget Computation for Selected Cities in North America,* 1967, Douglas B. Carter.

Films and filmstrips

Toward Inquiry — Teaching Earth Science is a 21 minute, black-and-white film produced by the Earth Science Curriculum Project for teachers. It introduces the investigative teaching approach developed with *Investigating the Earth.* The film shows the role of the teacher with actual classroom demonstrations. Two other films developed as adjuncts to *Investigating the Earth* are *Reflections on Time* (22 minutes, black-and-white) and *How Solid is Rock?* (22 minutes,

black-and-white). All three films are available from Encyclopaedia Britannica Educational Corp.

The *Basic Earth Science Program,* available from the Encyclopaedia Britannica Educational Corporation, Wilmette, Ill., is a set of motion pictures and filmstrips. These classroom aids were produced in cooperation with the American Geological Institute for upper elementary and junior high school grades. They are recommended for use with *Investigating the Earth.*

FILMS

Rocks That Form on the Earth's Surface
16 minutes, color.
Rocks That Originate Underground
20 minutes, color.
Heartbeat of a Volcano
20 minutes, color.
Erosion — Leveling the Land
14 minutes, color.
Evidence for the Ice Age
18 minutes, color.
Why Do We Still Have Mountains?
20 minutes, color.
Waves on Water
16 minutes, color.
The Beach — A River of Sand
17 minutes, color.
What Makes the Wind Blow?
16 minutes, color.
What Makes Clouds?
19 minutes, color.

FILMSTRIPS

Glaciers and the ice age

Investigating a Glacier
How a Glacier Shapes Its Valley
Reconstructing the Ice Age
Some Side Effects of the Ice Age

Fossils

How Fossils Are Formed
Collecting and Interpreting Fossils
Fossils and the Relative Ages of Rocks
Fossils and Prehistoric Environments
Fossils and Organic Change

Geologic measurements and maps

Measuring the Shape of the Land
Determining Sea Level
Measuring Movements of the Earth's Crust
Making a Geologic Map
Measuring Underground Temperatures
Measuring Differences in Gravity

Investigating rocks

Shale, Sandstone, and Conglomerate Coal
Limestone and Evaporites
Volcanic Rocks
Plutonic (Granitic) Rocks
Metamorphic Rocks
Recognizing Rock-Making Minerals
Comparing Rocks
Rocks and the Landscape

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167, National Park Service
169, Joseph Muench
170, Laboratory of Tree-Ring Research, University of Arizona
196, Diagram of tracks, George Ulrich
217, NASA
219, Hale Observatories
221, Lick Observatory
247, Hale Observatories
285, George Ulrich
286, George Ulrich

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